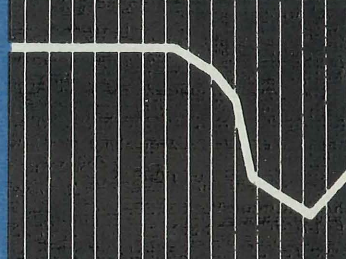
Industrial noise deafness; its influence on speech hearing

Gils, Jurriaan Johan Peter van

INDUSTRIAL NOISE DEAFNESS

its influence on speech hearing



J. J. P. VAN GILS

INDUSTRIAL NOISE DEAFNESS

ITS INFLUENCE ON SPEECH HEARING

STELLINGEN

I

Bij het aanpassen van hoortoestellen dient men aandacht te besteden aan de spreiding van het discriminatievermogen over de toonschaal.

II

De huidige ontwikkeling van de moderne micro-chirurgie van het oor wettigt het overwegen van een exploratie van het middenoor bij iedere geleidingsdoofheid, hetzij van bekende of onbekende oorsprong.

III

Vluchtige erythemato-pustuleuze huidverschijnselen welke bij een vrij aanzienlijk percentage der zuigelingen in de eerste levensdagen optreden, worden ten onrechte vaak geduid als een staphylococceninfectie.

IV

Bij de bestudering van de cytogenese van de plasmacellen wordt te weinig rekening gehouden met de mogelijkheid, dàt het ontstaan van antilichaamvormende cellen na een eenmalige toediening van antigeen anders verloopt dan bij een "secondary response".

V

Het in de laatste jaren zeer toegenomen aantal verkeersletsels maakt een doelmatige organisatie voor de traumatologie noodzakelijk.

VI

Het verdient aanbeveling bij patienten lijdende aan een fibroangioma nasopharyngeale een uitgebreid endocrinologisch onderzoek te verrichten.

VII

Het practische deel van de huidige medische opleiding is onvoldoende afgestemd op het uitoefenen van een normale huisartsenpractijk.

VIII

Een antibiotische of chemotherapeutische routinebehandeling bij acute streptococcenpharyngitis ter voorkoming van acuut rheuma, moet als overbodig worden beschouwd.

IX

Indien de klokketijd gedurende de zomermaanden meer in overeenstemming werd gebracht met de zonnetijd, zou dit de volksgezondheid ten goede komen.

Stellingen behorende bij het proefschrift van
J. J. P. VAN GILS
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RIJKSUNIVERSITEIT TE GRONINGEN

INDUSTRIAL NOISE DEAFNESS

ITS INFLUENCE ON SPEECH HEARING

PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR IN DE GENEESKUNDE
AAN DE RIJKSUNIVERSITEIT TE GRONINGEN,
OP GEZAG VAN DE RECTOR MAGNIFICUS DR. F. H. L. VAN OS,
HOOGLERAAR IN DE FACULTEIT DER WISKUNDE EN
NATUURWETENSCHAPPEN, TEGEN DE BEDENKINGEN VAN DE
FACULTEIT DER GENEESKUNDE
TE VERDEDIGEN OP WOENSDAG 30 MEI 1962
DES NAMIDDAGS TE 4 UUR

DOOR

JURRIAAN JOHAN PETER VAN GILS

GEBOREN TE DELFT

1962

DRUKKERIJ VAN DENDEREN
GRONINGEN

PROMOTOR: PROF. DR. H. C. HUIZING

Voor dit onderzoek werd financiële steun verleend door de Hoge Autoriteit van de Europese Gemeenschap voor Kolen en Staal te Luxemburg.

Aan de nagedachtenis van mijn Vader

Deze studie werd bewerkt in het Audiologisch Instituut (hoofd Prof. Dr. H. C. Huizing) van de Keel-, Neus- en Oorheelkundige kliniek (Hoogleraar-directeur Prof. Dr. Eelco Huizinga) van het Algemeen Provinciaal-, Stads- en Academisch Ziekenhuis te Groningen, in samenwerking met de afdeling Bedrijfshygiëne (hoofd K. R. Koopmans, arts) van de Geneeskundige Dienst der Nederlandse Steenkolenmijnen.
Medewerking werd verleend door de heer J. G. Kuipers van voornoemde afdeling Bedrijfshygiëne die, geassisteerd door de heer J. H. M. ten Have, de audiometrische onderzoeken verrichtte en de hierbij verkregen resultaten op nauwgezette wijze bewerkte.
De gehooronderzoeken geschiedden in de geluidsarme kamer van de Geneeskundige Dienst van de Cokesfabriek Emma te Beek-L. (bedrijfsarts C. B. N. H. Servaes). Het onderzoek werd verricht bij personen, geselecteerd uit een groot aantal personeelsleden van het Stikstofbindingsbedrijf te Geleen (bedrijfsarts H. J. Willems).
De vertaling in het Engels werd verzorgd door mej. T. Huizing, Emmen.

De verschijning van dit proefschrift vervult mij met grote dank jegens al diegenen die mij direct of indirect hun steun hebben verleend bij de totstandkoming hiervan.

CONTENTS.

Chapter I

SOME ASPECTS OF INDUSTRIAL NOISE DEAFNESS

Introduction

In the course of time a great deal has been written about the injurious influence the human body may undergo as a consequence of noise exposure and especially about its influence on the auditory organ. It would not be feasible within the scope of this thesis to give a complete survey of the pertaining extensive literature. Such a survey would be characterized only by incompleteness. A reference to one of the largely detailed literature studies which have appeared on the subject will be more to the purpose. (See lit. ref.).
In a short survey as will be given in this thesis only the most important facts concerning so-called *noise deafness* will be discussed.

Definition of noise

Before discussing the concept noise deafness, an attempt at a more exact definition of the concept *noise* seems necessary. Defining noise has given rise to many discussions and philosophical contemplations. The description of noise as "any unwanted sound" seems to be the most satisfactory yet. This does not alter the fact that this definition is equally incomplete, since the subjective interpretation of "unwanted" may individually vary strongly. Considering noise from a more physical point of view, it may be described as a complex system of all kinds of frequencies, continuously varying in intensity. In case of industrial noise and ambient noise we usually are concerned with low frequencies.

The sound intensity of noise is as a rule expressed in bel or decibel. As the zero of this decibel-scale a sound pressure of 2.10^{-4} dyne/cm^2 is chosen which corresponds with a sound intensity of 10^{-16} watt/cm^2. This is the lowest level of sound intensity at which the average normal ear (18-25 years of age) is just able to perceive a pure tone of 1000 Hz.

On the history of noise deafness

One of the first important publications on noise deafness dates from 1831, when FOSBROOK described the so-called "blacksmith deafness". In the second half of the nineteenth century a great many more systematic publications followed by the hand of numerous authors, concerning the same anomaly. The invention of steam-engines, explosion-motors and electro-motors involved a more and more frequent occurrence of noise deafness in various branches of industry. In the Netherlands in 1891 ZWAARDEMAKER described noise deafness in engine-personnel. In 1908 BEZOLD and SIEBENMANN described noise as the most frequently occurring cause of perception deafness. It is important to mention that they distinguished between two kinds of deafness:

1. A hearing loss resulting from a noise of short duration.
2. A hearing loss due to a long sustained noise.

The tests at that time were performed by means of tuning-forks, watch-ticking, spoken voice and whispered voice. Most authors then arrived at the following conclusions:

1. The sensitivity for both air- and bone-conduction has been reduced.
2. The Rinne test positive.
3. The distance at which whispered voice is just intelligible has become smaller.
4. The hearing loss is severest for high tones.

We should not omit here the remark of V. UFFENFORDE in 1922 who pointed out the great importance of the C_5 tuning-fork for tracing this perception deafness.

The problem was approached from another angle as well. Thus VON WITTMAACK and SIEBENMANN performed elaborate histological experiments of the inner ear of animals which had been exposed to noise.

More and more publications on noise deafness followed. An important Dutch publication appeared by VAN WAVEREN, describing the so-called gunner's deafness in navy-personnel.

From the attempts of the Belgian medical officer GILBERT, who in 1921 pleaded the institution of an international board of physicians who were to have admission to all factories, it became evident that the problem of noise deafness should not only be looked upon as something concerning otologists but rather as an industrial hygienic problem.

A great change was brought about by the development of the audiometer which made it possible to test the hearing function in a more accurate way than before. FOWLER SR. was the first to associate the hearing loss, which he had often noticed between 3000 and 4000 Hz, the so-called "dip" in this audiogram, with noise deafness. This finding was soon confirmed by many other authors (a.o. BUNCH). From that time onwards one speaks of the so-called C_5 dip which indeed characterizes noise deafness. BUNCH published in 1937 a detailed survey of the state of affairs at that time with regard to noise deafness. He also recorded the first results of extensive audiometric tests on large groups of persons, employed in various branches of industry, with a noise-induced hearing loss.

The discovery of the C_5 dip made a better judgment of noise deafness possible. A great number of important studies appeared in quick succession. On the part of the Dutch, DE WIT's thesis be mentioned in which there is also a record of audiological tests in navy-personnel.

More and more noise deafness turns out to be an industrial hygienic problem of the first rank. Not only appears noise deafness to be injurious to the auditory organ, but other deleterious effects may ensue as well. KRYTER who published in 1950 a very comprehensive literature study concerning the detrimental effects of noise, divides his monograph into three parts.

1. The deleterious effect of noise upon the auditory organ.
2. The disturbance of communication due to noise.
3. The effects of noise upon behaviour and labour performance as well as some other psychological, resp. physiological effects.

For a discussion in detail of all these effects be referred to the above-mentioned monograph. In this thesis only the injurious effect upon the auditory organ will be discussed.

Modern approach to the problem noise deafness

In various countries noise deafness has come to be regarded as a pure occupational disease in the legal sense, a compensation for damage or a compassionate allowance being paid to the afflicted person. In many countries, and in the Netherlands as well, one has not (yet) taken measures to that effect. The legal and medical problems attending it are numerous and have not been solved by far up to now. In the course of time, however, many scientific studies have been performed whereby attempts have been made to approach the solution of the problem in different ways. After LARSEN the different testing methods may be divided into:

1. Audiometric studies of large groups of persons all being employed in a certain branch of industry.

Elaborate tests in this manner are known from a.o. LARSEN (1939) who tested shipyard workers. Also from VAN LEEUWEN (1955) and BONJER (weavers) as Dutch investigators. In order to arrive at results well judgeable it is important to test groups of persons who have been exposed during a certain controllable period of time to the same kind of noise. Moreover, all persons who may have a hearing loss not induced by some sort of noise, should be excluded from the test.

2. Audiometric study of patients gathered from the clinic. Well-known studies are those by a.o. BUNCH and PERLMAN.
3. Experimental studies performed in the laboratory, the temporary threshold shift being examined in test persons after exposure to sound stimuli for some time. One may use for that purpose:

a. Pure tones (PEYSER, WILSON, DAVIS c.s., VAN DISHOECK and VAN GOOL, THEILGAARD a.o.).
b. Artificial noises such as octave band noises (DAVIS c.s., RUEDI and FÜRRER, HINCHCLIFFE, GLORIG c.s., a.o.).
c. Existing kinds of noises (DICKSON c.s., LARSEN, ROSENBLITH, KYLIN, VAN DISHOECK a.o.).

The main object of such experiments is as a rule the determination of the individual susceptibility to noise. We will return to the subject later on.

4. Histological investigation of the inner ear in case of noise deafness, similarly of animals after having been exposed for a longer or shorter time to a certain kind of noise. Important publications appeared by WITTMAACK, SIEBENMANN, by HABERMANN in 1890 and 1906, by CROWE, GUILD and POLVOIGT in 1934 and by RUEDI & FÜRRER in 1947.

In spite of many elaborate studies, performed in the course of years by numerous people, a great many problems in noise deafness still remain unsolved. The most important of these problems and especially those overlapping the field of industrial hygiene, will, among other things, be discussed in this chapter.

Testing the hearing function

As appeared from the preceding discussion, the development of the audiometer involved quite a revolution in hearing test methods, whereas formerly tuning-forks, whispered voice and spoken voice were used. Especially the whispered voice test played a very significant part in these, now out-dated, methods. Numerous medico-legal tests were and are, unfortunately, still based on this method.

Experiments by a.o. FOWLER, GLORIG, KRUISINGA have proved, however, that this method was far from accurate. The following remarks may be made about it:

1. There is no proportionate decrease of the presented whispered voice intensity when the distance is enlarged. In open space the sound pressure decreases in proportion with the square of the distance to the sound source. This is not true, however, for an enclosed space.
2. Numbers for word stimuli are less adequate because of their quantitatively as well as qualitatively divergent sound value. Better are the *equi-zonal* and *equi-intense* test words designed by ZWAARDEMAKER and QUIX. These are words chosen in such a way that the words of one and the same group have a more or less equal intensity and also a cognate spectral energy distribution.
3. With different speakers the intervariance in speech intensity will be great. Similar variations exist in the same speaker under different circumstances.

Important in this respect are also the observations of KRUISINGA and HUIZING. They demonstrated, i.a. by means of speech audiometry with whispered voice, that in perception deafness a *vocal inversion* may occur. This vocal inversion is charaterized by the fact that, unlike normally, spoken voice is sometimes understood at lower intensities than whispered voice. The explanation is to be sought in that persons with a perception impairment in most cases have a high tone loss by which whispered voice (i.e. voice deprived of low frequencies) is relatively not so well understood.

From the above-mentioned it may appear that the whispered voice method as an accurate medico-legal test of the hearing organ is to be rejected.

The introduction of the audiometer, as said before, brought about an important improvement in the test methods. Nowadays two prominent test methods are known, the so-called threshold audiometry and speech audiometry. Both methods are necessary for a detailed hearing test.

1. THRESHOLD AUDIOMETRY

In case of threshold audiometry electrically generated pure tones are used, enabling one to determine either the smallest intensity or the highest resp. lowest frequency at which these tones can be just perceived by the ear. For in principle two fundamentally different types of threshold audiometry are known:

a. *The so-called octave audiometry*

At *constant frequency* the intensity of the presented stimuli is *continuously* varied. This is subsequently repeated at other frequencies. It is not at all necessary for these frequencies to represent successive octave values. With the help of the obtained threshold intensities an audiogram is made up.

b. *The so-called continuous audiometry*

At *constant intensity* beyond normal threshold the frequency is here *continuously* varied. This is continually repeated at various intensity levels, the corresponding threshold crossings being established. With the help of the obtained threshold frequencies an audiogram is made up.

The nomenclature of the two types of threshold audiometry may lead to misinterpretations. It seems, therefore, useful to discuss this matter.

The present-day term *octave audiometry* has, as a matter of fact, become obsolete and is therefore deceiving. Nowadays by means of modern audiometers one is able to determine thresholds for practically all frequencies, whereas formerly thresholds were ascertainable only at 125, 250, 500, 1000, 2000, 4000 and 8000 Hz. For a detailed hearing test these frequencies only are insufficient. VAN DISHOECK who, as it were, rediscovered the continuous audiometry and adapted

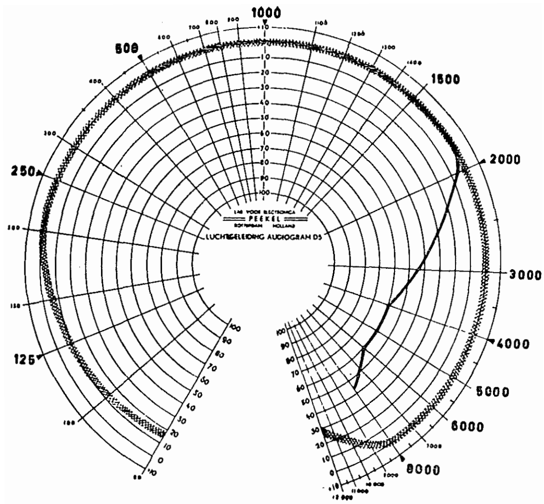

Fig. 1A

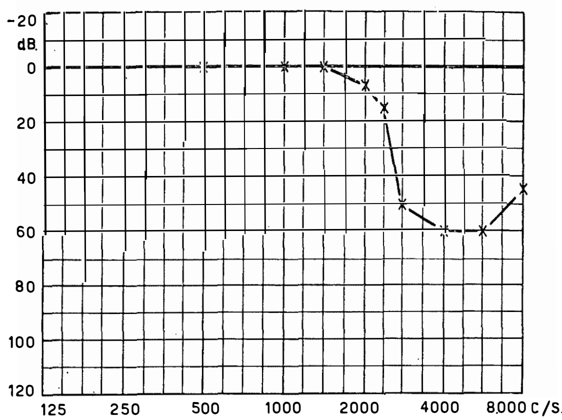

Fig. 1B

Perceptive impairment resulting from exposure to industrial noise.
A. Octave = I.V. threshold audiogram (A.C.).
B. Continuous = F.V. threshold audiogram. (A.C.).

it to practical application, pointed out that most of the beginning noise traumata are not characterized by a dip at 4000 Hz, but are in initial stages indeed characterized by dips somewhere in the frequency area between 4000 and 8000 Hz. So this comprises an area in which no threshold is determined in case of octave audiometry. Therefore this octave audiometry is in the true sense of the word incomplete, hence that this test should be completed with threshold measurements at 1500, 2500, 3000, 5000 and 6000 Hz. Performed in this way this testing method may be quite satisfactory. The test itself is not very tiring for the subject and will not take up much time from the experienced tester.

The term octave audiometry, however, has no meaning at all.

Continuous audiometry, much practised in the Netherlands by industrial hygienists, has the advantage over "octave audiometry" of ascertaining thresholds all over the tone-scale. This may be useful, especially when tracing beginning noise traumata. For the latter bear a frequency-selecting character and this implies that they are better detected by means of a method, in which the *frequency is varied continuously* in stead of a method, in which the *intensity is changed continuously* as is the case in octave audiometry.

Viewed in this light, we may conclude that *the term continuous audiometry does not say much either.* For a proper discrimination of both methods, *octave* audiometry and *continuous* audiometry, it would therefore be more accurate to change these terms into *intensity variable* and *frequency variable threshold audiometry (I. V. and F. V. threshold audiometry).*

The frequency variable audiometry is to be preferred to the intensity variable audiometry when one wants to determine very quickly whether a certain amount of hearing loss somewhere in the tone-scale is just reached or exceeded. Is the audiometer adjusted to a certain intensity level above normal threshold then one "Sweep" all over the tone-scale is sufficient to find out whether each tone can be heard at this intensity. This so-called "Screening" is of special importance to large factories where it is often desirable to obtain in a rapid and convenient way an impression about the function of the auditory organ.

The advantages and disadvantages of the two methods may be dicussed at length. Both have their pros and cons. Our impression is, however, that the extensive octave audiometry is eventually less tiring for the subject. As to this, opinions may differ.

Quite another point of purely theoretical nature is whether the results, obtained through the two methods, may be considered equivalent, since the method of stimulation of the auditory organ in octave audiometry is totally different from the one used in continuous audiometry. With the first method the stimuli are presented at a fixed frequency with varying intensity, in case of the second method at varying frequency with fixed intensity level above normal threshold.

As long as only little is known about the exact process taking place in the cochlea in either case of testing, is does not seem correct, theoretically spoken, to regard the results of both ways of stimulating the auditory organ as equivalent.

When this purely theoretical point is borne in mind, it only rests to remark that it is recommendable to perform threshold testing always according to one of the two methods and never to consider both methods just comparable. In this way the choice between the two remains a matter of personal preference.

GLORIG, director of the American research center of the subcommittee on noise in industry, in 1958 pleaded once more a greater uniformity in the methods of hearing tests in the various industries. It were to be wished that a certain standardization would be effected because only then a reliable statistic analysis is possible of the thousands of results acquired by means of hearing tests in the various industrial branches. That is why it is, especially in the Netherlands, where also continuous audiometry is much applied, necessary to restrict oneself to *one single method* of testing, either the extensive *octave (I.V.)* audiometry or the *continuous (F.V.)* audiometry. Accordingly, in our country attempts have been made, under supervision of the T.N.O., to achieve this end.

2. SPEECH AUDIOMETRY

A second method of auditory testing, as indispensable as the first, is speech audiometry. Threshold testing only yields limited data on the hearing function. The test tells us practically nothing about that function of hearing which is socially from such an importance, namely, speech hearing, for this is a process taking place not on threshold level, but well above it. So speech audiometry aims at an investigation of speech hearing. In the Netherlands, in 1950, REIJNTJES has described this method and its practical applications for the Dutch language in detail.

When performing speech audiometrical tests, so-called phonetically balanced word lists (P. B.-lists) are i.a. used. The words of these lists have been selected in such a way that the frequency of occurrence of its phonemes has the same percentage as in common spoken language. These P. B. lists are presented to the patient at different intensity levels, while the number of words repeated correctly is taken down. The *articulation score* can be evaluated in this way. Such articulation scores plotted out in a curve as function of the speech intensity, determine the so-called articulation curve (SILVERMAN and DAVIS). REIJNTJES described three kinds of curves, the C, P and R type. (fig. 2).

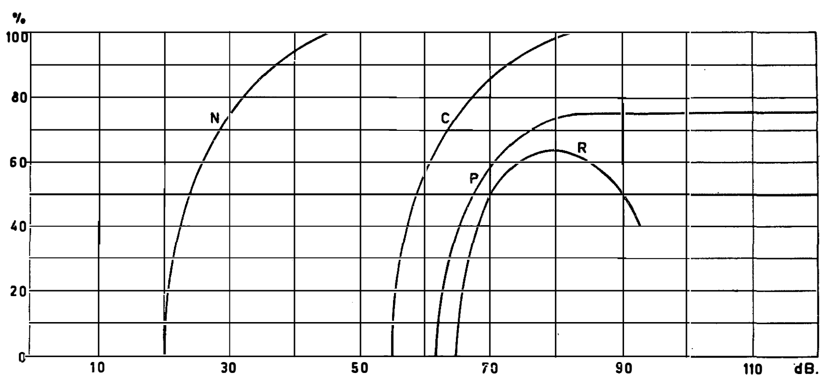

Fig. 2.

Examples of different speech audiograms. (according to REIJNTJES).
N. = Normal speech audiogram.
C. = Speech audiogram in a case of conduction deafness.
P. = Speech audiogram in a case of perception deafness.
R. = Speech audiogram in a case of perceptive deafness with recruitment.

The C type is found in conduction deafness. It is true that the articulation curve has the same shape as in cases of normal hearing, but has shifted to the right. Provided the intensity is sufficient, full intelligibility remains possible.

This is altogether different in the P and R type which refer to perception deafness. In the P type the articulation curve has shifted to the right as well. An articulation score of 100 %, however, is usually not reached. At a certain intensity a saturation effect appears to ensue so that, at a further increase of intensity, the articulation score, remains the same. In the so-called R type this articulation score again decreases at a further increase of intensity. In this way a so-called helmet-shaped curve has come into being while there is an optimal intelligibility level.

Thus in general in the P as well as in the R type full 100 % intelligibility cannot be attained. The difference between the 100 %-score and the maximal score is called *discrimination loss.* Such a discrimination loss which consequently is to be found only by means of speech audiometry, only exists in perception deafness. So the fact that in this type of deafness full intelligibility in most cases is unattainable, is unlike in cases of conduction deafness, not a matter of insufficient loudness of the presented speech, but of a hampered discrimination of the speech sounds. We will dwell upon the factors which may effect this hampered discrimination later on.

Although it follows that speech audiometry is indispensable for a proper determination of the hearing function, this method is also attended with considerable disadvantages. We will come back to this when discussing the social validity.

Audiometrical group testing

In group testing, as is necessary in industry, we should strive for as short a duration of the test as possible. For that purpose mobile soundproof testrooms may be used, which can be placed as close as possible to the workroom of the employees who are to be tested. This has the advantage of keeping the employee from his work as short as possible. Moreover there are yet more methods of testing at our service which may mean a considerable gain of time.

a. *Screening audiometry*

The screening method furnishes a convenient and short method for tracing hearing losses.
In case the continuous audiometer is adjusted to 15 db, then taking measuring mistakes and subjective differences in normally hearing persons into account, hardly speak of actual hearing losses.
In case the continuous audiometer is adjusted to 15 db, then through a "Sweep" all over the tone scale, a hearing loss may be detected, for when the tone is perceived uninterruptedly then a possible existing threshold level elevation is in any case less than 15 db.

If required, a similar test can also be carried out in a group of persons.

b. *The oto-check 4000 Hz*

Although the screening method means a considerable shortening of the threshold test, even more simple methods have been searched for in which, if possible, the testing of only one frequency would suffice.

On account of their experience that in 98 % of cases of noise deafness the largest hearing loss is observed at 4000 Hz, the Americans HOUSE & GLORIG introduced in 1957 the so-called oto-check. This is a simple instrument which enables one to present very rapidly at choice three different intensity levels at 4000 Hz. It stands to reason that this test aims at nothing else but supplying a quick and convenient means to trace a noise trauma.

Once a loss has been detected it should always be followed by a complete threshold audiogram. This holds, for that matter, for each type of screening.

According to GLORIG's report, the oto-check results were found to be satisfactory. The test time is only 20 seconds; trained operators are not necessary while the test may be performed in any relatively quiet environment, as waiting rooms, first-aid rooms etc. At a screening level of 20 db intensities of 85 db can still be permitted without masking the 4000 Hz tone.

c. *Automatic audiometry*

The need for performing more rapidly and with less well trained operators a reliable hearing test has, as it was bound to happen in this era of automatization, led to automatic audiometry. For that purpose several ingenious systems have been devised.

The usefulness of the automatic audiometry depends upon the conditions one has made with respect to it. So far as the patient is concerned, automatic audiometry does not save time. Concerning the operator it does save time, because one person is able to test more people at the same time. If necessary, more automatic audiometers may even be operated by one person at the same time. Consequently automatic audiometry certainly presents great advantages, reason why a number of large industrial plants have proceeded to purchase these apparatus which, after all, are very expensive.

From the preceding description of various methods which may be applied in hearing tests, it indeed becomes evident that the tone threshold test may be considerably shortened and simplified, that is, if we are just concerned with the detection of a possible noise trauma. The supplementary speech audiometrical investigation, however, will yet take up much time.

The various types of acoustic traumata

The term acoustic trauma has in the course of time more than once given rise to confusion. At the congress of the International Society of Audiology held in Padua, in 1958, RUEDI tried to classify the various terms which gradually have become current.

On the basis of physical measurements and with the help of clinical observations he suggests to divide the noise-induced hearing traumata after etiology into: 1. noise trauma.
2. detonation trauma.
3. explosion trauma.

The Americans distinguish in about the same way at the suggestion of DAVIS between:

A. Occupational hearing loss. This corresponds to RUEDI's noise trauma.

B. Acoustic trauma. This comprises both the detonation and explosion trauma.

Ad. 1. The *noise trauma* originates as a consequence of long term exposure to noises. The composition of a noise and the time of exposure determine i.a. the magnitude of the trauma. A progressive inner ear deafness will arise, characterized by the typical shape of the threshold audiogram. For a restricted high tone loss will come into being, the so-called "dip", which usually has its maximum between 4000 and 6000 Hz. The longer the noise exposure, the wider and the deeper the "dip" becomes. Eardrum aberrations are not found. Usually the subjective complaints only start at a later stage. Sometimes the patient is complaining of tinnitus, sometimes of a feeling like having plugs in the ears. After cessation of exposure to noise, hearing may be entirely or partially restored.

The noise trauma is mostly seen to occur in industry.

Ad. 2, 3. The *detonation trauma* and *explosion trauma* are not produced by a noise of long duration but the cause is a very short term noise exposure.

According to FÜRRER there exists between a detonation and an explosion only a quantitive but no qualitative difference. This difference is determined by the duration of the produced pressure wave.

Clinically the detonation trauma is characterized in almost the same way as the noise trauma. Here we also find the typical "dip" in the audiogram. In most cases the hearing loss is of sudden onset. The conduction system of the middle ear is not affected. Once in a while petechial bleedings at the eardrums are observed. The trauma being sufficiently severe, the patient complains of deafness. Tinnitus attends these complaints as a rule for months or even for years.

This detonation trauma will chiefly be found in the military service.

Quite different is the clinical pattern of the explosion trauma. Here also a perception impairment will be found. The audiogram, however, is not characterized by a "dip" but usually we have to do in this case with a strongly sloping threshold curve at 2000 Hz. Often this deafness is attended by a conduction deafness. Eardrum aberrations in the form of perforations are of frequent occurrence. The perception loss is as a rule definitive.

We will now go further into the matter of the various factors promoting the occurrence of the *noise trauma.* Special attention will be paid to the industrial hygienic aspects of noise deafness.

Hearing loss resulting from industrial noise

Two types of hearing loss should be distinguished, namely:

1. temporary hearing loss.
2. permanent hearing loss.

Temporary noise deafness may be defined as a hearing loss produced by exposure of the ear to a certain source of noise. This hearing loss should disappear after a certain arbitrarily established period of time. Suggested by GLORIG a.o. this period of time is fixed at 16 hours after termination of the noise exposure. This length of time is not chosen arbitrarily but specificially refers to the temporary hearing losses which may occur after exposure to industrial noise. So the temporary hearing loss is that hearing loss which is determined at the end of one working-day and from which the ear has completely recovered at the beginning of the next working-day, so as a rule sixteen hours later. Has this hearing loss disappeared only partly, then the residual hearing loss is called permanent.

On account of this temporary threshold shift (Temporary Threshold Shift = T.T.S.) which should be looked upon as a certain fatigue, extensive experiments have been performed. Numerous publications on it are known: a.o. by EWING & LITTLER, PERLMAN, DAVIS c.s., RUEDI & FÜRRER, VAN DISHOECK & VAN GOOL, KYLIN, GLORIG c.s. and many others. It would lead too far to discuss the results of all these experiments in detail. Therefore we will confine ourselves to the most important findings, having emerged from these experiments:

1. The magnitude of the T. T. S. depends upon the intensity, duration of exposure and the spectral composition of the sound stimulus.
2. T. T. S. as a result of a pure tone occurs at a frequency which is located half an octave above the stimulating tone. Fatigue resulting from octave band noises occurs within the used octave band and the subsequent higher octave band.
3. In order to evoke fatigue with low frequencies, much more intensity is necessary to arrive at the same result as with high frequencies. From this it may be inferred that high tones have a more traumatizing effect than the low ones.
4. T. T. S. will occur soonest immediately after the initiation of the noise exposure. Afterwards the amount of hearing loss will increase only slowly.
5. Recovery after termination of the exposure starts rapidly but gradually progress will be only slow. Sometimes recovery is very irregular. In extraordinary cases recovery is most retarded at frequencies near 4000 Hz.
6. As far as the magnitude of the T. T. S. as well as the degree of recovery are concerned, there exist large individual differences. It is true that the findings for each separate individual are fairly constant but they may be at variance as well.
7. The occurring temporary hearing loss always shows the regression symptom.

The relation between temporary and permanent hearing losses

Regarding the relation existing between temporary and permanent hearing loss various investigators (a.o. GALLAGHER & GOODWIN, ROSENBLITH, DAVIS) have, on good grounds, assumed the following:

1. A noise not causing a temporary threshold shift will not cause a permanent threshold shift either.
2. The *permanent* loss resulting from long term noise exposure will probably not be larger than the *temporary* loss produced by a short term exposure to the same noise. The configurations of the audiograms displaying temporary and permanent losses, will be about the same. Noteworthy are in this respect the observations taken by VAN LEEUWEN. When comparing "morning" and "evening" audiograms of industrial workers who had experienced noise exposure for less than three months, the evening-audiogram appeared to bear some resemblance to the audiograms of other employees who already had sustained a permanent hearing loss induced by the same noise.

The correctness of the above mentioned hypotheses can hardly be questioned after the very extensive studies GLORIG and his cooperators carried out.

GRAVENDEEL and PLOMP also share the view, as appears from a recent publication, that there exists a certain relation between the temporary and permanent hearing loss, as long at least as this is produced by continuous steady noise.

The existence of a relation between permanent and temporary hearing loss is not only of theoretical importance but also of very great practical value, since after the study of the temporary threshold shifts which may be caused by a type of noise under certain conditions, it presents the possibility of predicting the permanent hearing damage which may be brought about by this specific kind of noise.

On the basis of the above-mentioned relation one has also tried to establish a so-called damage risk criterium which is to state the borderline between injurious and non-injurious noise levels. We will come back to this subject later on.

Factors determining the hearing loss

Several factors, partly based on the above-mentioned observations on temporary and permanent noise-induced hearing losses, may be indicated determining the magnitude of the concerning noise trauma.

1. THE FACTORS DETERMINING THE PROPERTIES OF THE NOISE

A. *The intensity of the noise*
In general it may be said the higher the intensity the more serious the hearing loss will be. When discussing the so-called D. R. C. (Damage Risk Criterion) which establishes the borderline between injurious and non-injurious noise, we will again refer to this factor.

B. *The frequency spectre of the noise*
Regarding industrial noise, MC COY in 1944 pointed out on the strength from industrial observations that noise with a high tone character is more deleterious than noise with a low tone character. Similar results were also obtained by experiments in which the T. T. S. was measured which had come into being after exposure of the ear to noise concentrated in narrow octave bands, focussed resp. in the higher and in the lower part of the tone scale. So when measuring the intensity of the noise the ascertainment of an over-all intensity level is not enough but the distribution of the intensities over the tone-scale should also be evaluated. For that purpose one makes use of so-called octave band filters. If required the sound pressure may also be measured in even more narrow bands, e.g. $^1/_2$ or $^1/_3$ octaves. In order to assess the D. R. C., this octave band analysis has significant consequences.

C. *The continuity of the noise*
It makes a great difference whether a noise has a continuous steady or fastly intermittent character. It has been stated that a continuous noise is less traumatizing than noise of the same intensity and composition but of intermittent character.
This is probably connected with the time necessary for the reflectory contraction of the middle ear muscles which are to protect the inner ear partly from hard noises.
This time which is alleged to be 11 msec. may be longer than explosive noises of short duration. In this way the unprotected ear will be directly exposed to such noises.

2. THE TOTAL TIME OF EXPOSURE, THE DURATION OF THE EXPOSURES EACH TIME AND THE REST-PERIODS BETWEEN THE EXPOSURE-PERIODS

The many experiments which have been performed in large groups of industrial employees working in noisy environments, demonstrated that as years of service increase the amount of hearing losses becomes larger (GARDNER). From accurate tests (VAN LEEUWEN, GLORIG & DAVIS), however, it becomes obvious that the largest noise induced threshold level elevations occur in the first years of employment. Afterwards the increase of hearing loss will only be very slow. A great part of the loss sustained in later years, however, should be ascribed to presbyacusis. We will return to that matter later on. The duration of the noise exposure each time and the rest periods in between, also determine in part the extent of the total hearing loss.

From the discussion of the experiments concerning the T. T. S. it has already become apparent that after a shorter or longer rest period there will be a certain degree of recovery. Incidentally, however, cases occur in which recovery fails to come (URBANTSCHITSCH, VAN DISHOECK). In 1958 GLORIG performed a very detailed comparative investigation in jet mechanics and industrial employees. This investigation showed among other things that the hearing losses occurring in the first group were significantly smaller than those in the second group. This in spite of the fact that the intensity of the noise to which the jet mechanics were exposed is considerably higher than that experienced by industrial workers. The spectral composition of both the two noises was about the same. The author mentioned is of the opinion that this difference in hearing loss is not only the result of better ear protection (ear plugs, muffs) on part of the jet mechanics, but rather of the different time distribution of the noise exposure to which the different groups were subjected. Concluding it may be said then, that exposure to a continuous specific noise for many consecutive hours is more injurious to the auditory organ than exposure during the same total time period but interrupted by rest periods. It is, accordingly, assumed that a constant noise-induced hearing impairment is more liable to occur when the ear is again and again exposed to noise so soon, that the damage of the preceding exposure has not yet been restored.

Evaluating the total time of exposure and the correspondent time distribution is an important task but hardly feasible in practice.

The ideal way to approach the problem of the noise trauma in industry is working out many data obtained from hearing tests and noise measurements in various branches of industry. In order to arrive thereby at reliable conclusions, however, one should have thousands of comparable audiograms at one's disposal. This means that the method of hearing testing and noise measuring should be uniform as much as possible. The great difficulty, however, remains the establishment of the total time of exposure. Most employees frequently work in different, more or less noisy environments, the degree of noise in the same workroom being liable to substantial variations as well. This makes a good judgment of the test result often particularly difficult. So the best thing is trying to find large groups of people, who, for many consecutive years are continually under equal conditions exposed to the same noise. According to statements from BONJER weavers lend themselves quite well to such testing.

3. THE INDIVIDUAL SUSCEPTIBILITY

The answer to the question whether persons with a certain pre-existent ear disease are either more or less susceptible to noise than persons with normal ears, has more than once given rise to contradictory statements.

Some investigators as PERLMAN, SACHER, BRUÏNE-ALTES see in the existence of a conduction deafness having resulted from e.g. a chronic otitis media, a protection of the inner ear because this causes less energy to be transmitted to the cochlea. Others as DAVIS and LARSEN see no difference in susceptibility, while PEYSER and also LINK think that chronic inflammations of the middle ear involve an increased susceptibility. LINK's opinion, based on these observations, is that the pneumatization of the mastoid determines the susceptibility of the ear.

Up to now it is not yet very clear whether these middle ear aberrations are protective or not, though one is inclined to assume that this is the case indeed. Still, when placing persons with an existent ear disease in noise, one should use great care, since a possible in a slight degree occurring noise deafness may just suffice to result in a serious social handicap.

Without the question of a pre-existent ear disease, TEMKIN already thought to descry differences in the individual susceptibility to noise. For a long time one has been in search of some parameter characteristic of individual susceptibility. PERLMAN and SACHER supposed that elderly persons were more susceptible than young ones. According to VAN LEEUWEN, however, the deafness occurring at a later age must be ascribed for the greater part to presbyacusis, which could be confirmed by recent investigations by GLORIG and DAVIS.

Other investigators (KRISTENSEN, CIOCCO) tried to find out whether one's constitution could possibly be influential. The results, however, are contradictory. From recent tests by a.o. KYLIN and DIEROFF it might be indicated that men are more susceptible to noise than women.

Assessing the individual susceptibility by means of a test was first suggested by TEMKIN. In the course of history several of these tests have thereupon been published. Most of them are based on exposure of the ear to a short stimulus after which the extent of the temporary threshold shift *(fatigue)* and in some tests the speed of the resulting *recovery* as well, determines the individual susceptibility. As exposure stimuli may be used:

1. Pure tones.
   (PEYSER, WILSON, THEILGAARD, VAN DISHOECK & VAN GOOL, JERGER & CARHART).
2. White noise.
   (WHEELER, CHRISTIANSEN, GALLAGHER & GOODWIN).

Important objections can be raised against such tests:

a. Not all test persons will give the maximum loss at the same frequency.
b. The magnitude of the dip and the degree of recovery often differ considerably in the same test persons at various tests administered under equal conditions.

3. According to statements by VAN DISHOECK and VAN GOOL a.o. one had better use as exposure stimulus noise from the department where the person concerned will be employed. Undoubtedly there is a great deal of truth in the thought of testing the individual susceptibility by means of industrial noises and not by pure tones or artificial kinds of noises. Practically, however, such a test is difficult to perform.

Next to the above mentioned noise susceptibility tests, several other methods based on different principles have been proposed. Up to now, however, the general opinion is that none of the proposed susceptibility tests are fully reliable, or in the present form suitable for use in industry.

Apart from that determining the individual susceptibility does not seem such an urgent problem any longer. From investigations by GLORIG and his cooperators it seems assumable that, in contrast to our former views, an extreme susceptibility to noise, like an extreme insusceptibility only occurs very seldom.

It is true that there are individual differences, but nothing is known about the distribution of these differences over the entire population. Two curves can be drawn according to which the susceptibility distribution may proceed. Such curves are shown in fig. 3. Curve A seems to be most probable. This is the normal distri-

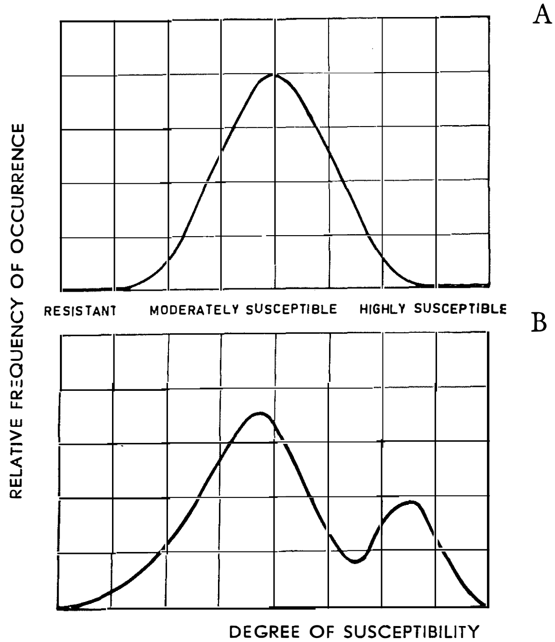

Fig. 3.

Distribution of the degree of susceptibility to noise induced hearing loss.
A. : A normal distribution.
B. : A bimodal distribution.

bution according to which biological reactions as a rule will take place. In that case a clear dividing-line between extreme susceptibility and moderate susceptibility, cannot be indicated. This would be much easier if a distribution according to curve B were found.

As long as this last distribution cannot be proved with certainty we have reason to assume that the occurrence of extreme susceptibility is ever rare. Trying to find a reliable susceptibility test for tracing these few extremely susceptible ears does not seem to make much sense. Endeavouring to protect the much larger group of moderately susceptible individuals seems to be better and more to the purpose. The search for a really reliable Deafness Risk Criterion appears to be the most important means to that end. This does not alter the fact of course, that one should always be on the alert to trace extremely susceptible ears as soon as possible. Therefore, regular audiometric control of industrial employees is desirable.

Summary of the concept noise deafness

Summarizing the foregoing observations the following description of noise deafness as a result of industrial noise may be given:

Noise deafness is a perception deafness characterized by a hearing loss in the high tone region. The greatest threshold level elevation will be found near 4000 Hz. The threshold audiogram shows a so-called "dip". At first the hearing loss may be temporary, after termination of the noise exposure recovery is possible. When, sixteen hours after termination of exposure, recovery is only partial, then the remaining hearing loss has a permanent character. The amount of hearing loss depends mainly upon the following factors:

1. The frequency spectre of the noise.
2. The over-all intensity of the noise, as well as the intensity in different frequency bands.
3. the character of the noise (e.g. continuous or fastly intermittent).
4. The duration and nature of the noise exposure.

Diagnosis and differential diagnosis of noise deafness

DIAGNOSIS

The diagnosis of noise deafness may be most difficult. It would be easier if a diagnosis merely based on the threshold audiogram were sufficient. This is, however, only possible if it differs fundamentally from audiograms of every well-known factor causing hearing loss. Since this is not the case, it is indeed the anamnesis which is of very great significance. In particular attention should be paid to a few anamnestical facts:

1. Working in noisy environments.
2. The course of complaints.

A sudden initiation of deafness mostly points to a detonation trauma or explosion trauma unless it is a matter of extreme susceptibility on part of the patient. Usually deafness will progress so gradually that the afflicted person does not invoke medical aid before a very late stage. When it has come as far as that, the hearing loss will usually be serious; often the patient's hearing loss has to be brought under his notice by relatives or acquaintances.

3. Attending dizziness.

Dizziness points as a rule to deafness of sudden onset. In real noise deafness it is seldom found.

4. Attending tinnitus.

Complaints about tinnitus mostly occur at the initiation only of employment in noise. As a rule it is attended by a feeling like having a plug in the ears. After a short period of rest this complaint is usually not heard anymore.

5. Mostly the hearing loss is symmetrical although, in some cases asymmetry wil be found. From the anamnesis it may become clear that this is the result of a certain position of the patient with respect to the source of noise. Such findings may be highly helpful for the diagnosis.
6. Further anamnestical data can be drawn from an analysis of the kind of noise in which the patient has to work.
7. Finally it will be important to inquire after other possible causes of deafness (oto-intoxication, congenital impairment etc.).

After the anamnesis follows:

1. The examination of nose, throat and ears (cerumen, middle ear aberrations etc.). The ear drum in case of noise deafness is always grey and intact.
2. The threshold audiogram.

In order to get an impression as to the permanent character of the hearing loss a threshold audiogram should be made up at least

16 hours after termination of the noise exposure. After that the test should be repeated several times. The threshold, as mentioned before, is characterized by the so-called "dip".

3. The speech audiogram.

Merely as a means for diagnosing noise deafness this test is of little value. When, however, it is also a matter of determinating social validity, then this testing method is indispensable. An increase of the speech intelligibility threshold, as well as discrimination loss can only be ascertained by means of the speech audiogram.

4. An investigation after the recruitment symptom may also prove helpful for the diagnosis. In all cases of noise deafness recruitment is found. (BRUÏNE-ALTES).

When one wants to form an impression as to the extent of the noise trauma, then a correction (dependant upon age etc.) might be needed for perception losses resulting from socio-acousis and presbyacusis. This correction may be applied according to the view that socio-acousis, presbyacusis and noise deafness, are additive losses (GLORIG, ROSENBLITH). We will return to this subject when discussing the differential diagnosis.

THE DIFFERENTIAL DIAGNOSIS

Many other types of perception deafness may present difficulties in diagnosing noise deafness. The shape of the threshold audiogram together with the anamnesis may indeed often be sufficiently supporting, but the occurrence of the so-called dip is by no means pathognomic for noise deafness.

Dips with a max. between 4000 and 6000 Hz. are sometimes found in congenital as well as in acquired types of perception deafness. Spontaneous dips sometimes disappearing, sometimes of permanent nature, have been described. For the diagnosis of pure noise deafness all these types of perception deafness should be excluded (intoxication, cerebral affections, detonation traumata etc.).

Besides the solitary occurrence of noise deafness it will also often attend other types of perception loss. So a combination with hearing losses related to age is possible. From the individual audiogram it usually cannot be concluded to what extent this factor concerning age is playing a part. Still this may be very important, especially so when it is a matter of an accurate assessment of pure occupational damage. Among the perception losses associated with age are reckoned:

a. presbyacusis,

b. sociocusis.

ad. a. Pure old-age deafness, a hearing loss as a direct result of the physiological aging process, is characterized by:

a. a sloping threshold audiogramcurve,

b. no recruitment,

c. diminished speech hearing capacity.

ad. b. In order to be able to compose for different age-groups average hearing threshold curves of persons who had never been working in noise, various mass tests have been performed. In America some of these tests have been carried out at state fairs. A well

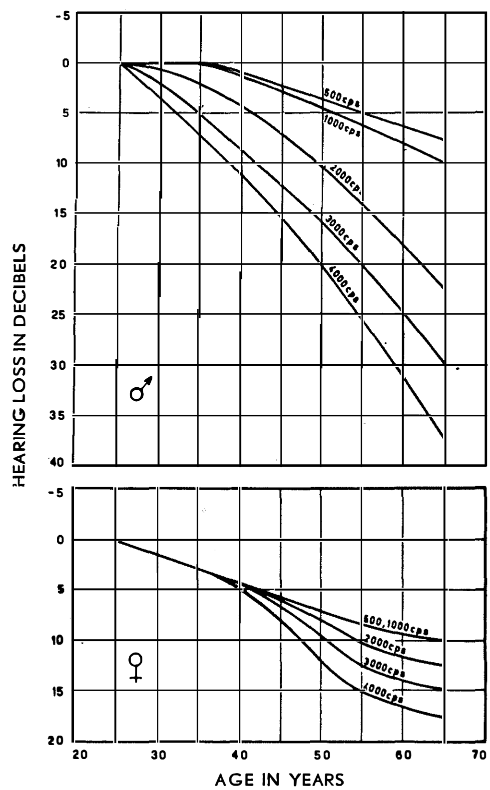

Fig. 4.
Hearing loss as a function of age in men and women.

known investigation has been done under the direction of GLORIG, at the Wisconsin state fair in 1954. From these tests it became evident that for each age-group there exists a significant difference between hearing losses in men and those in women. Again and again women appeared to have a slighter hearing loss than men. The curves as they have been drawn up by GLORIG are shown in fig. 4. The fact that men show a larger hearing loss is, according to GLORIG, to all probability the result of noise exposure, which a male person on account of his social function, is easier subjected to than females. By virtue of the experience gained, GLORIG pointed out that the relation between hearing loss and age, besides being a result of physiological changes in age, is also caused by noise exposure, which one has inevitably to endure owing to everyday social life situations.

The hearing loss caused in this way is called, at the suggestion of GLORIG, sociocusis. Etymologically the term *Socio-acousis* is to be preferred. Both presbyacusis and socio-acousis are unavoidable hearing losses, not at all related to occupational activities. A distinct separation between these two losses seems difficult to realize, but is of little practical importance. In order to be able to separate noise deafness from presbycusis and socio-acousis, one should start from the generally accepted, but by no means proved hypothesis, that we have to do with additive losses here.

Considering this supposition to be correct, the actual amount of hearing loss can be established according to:

a. Measurement of the total hearing loss.
b. Correction by substracting (from the total loss) the hearing loss which must have originated owing to presbyacusis and socio-acousis (see fig. 4).

Summarizing we may say that the diagnosis of noise deafness, as well as assessing the exact extent of the loss is not very simple.

As a rule the diagnosis and also the determination of the extent of the traumatic hearing loss is based on a large degree of probability but not on certainty.

As a matter of fact one cannot be satisfied, however, **with this** large degree of probability. For as soon as one is going to consider noise deafness as a pure occupational deafness in the legal sense and consequently one proceeds to the payment of compensation claims, a correct assessment of the magnitude of the pure traumatical loss will be of far reaching consequence on the amount of compensation to be paid. It is, therefore, the more important not to neglect the performance of an extensive hearing test *before* the actual employment of each employee who is to work in noisy environments. Making up such a pre-employment audiogram does not only prove to be sometimes an important diagnostic aid later on, but also provides the employee with an important document to ascertain the traumatic loss.

The borderline between injurious and non-injurious noise levels in industry

An important question which every employer should consider is: "Is it possible that in my factory noise deafness may originate as a direct result of noise caused by my production-system?"

To answer this question two things may be done: Either waiting until an employee reports hardness of hearing, or performing after a certain time a hearing test on the employees with the possibility of diagnosing in this way a specific hearing loss. In both cases one is, as a matter of fact, already too late as the anomalies which have been detected may be irreversible. In the first case a very considerable amount of hearing loss will already be present since, as has been mentioned before, complaints due to noise exposure will not be met with until at a later stage. In the second case the aberration may in favourable cases be limited to a slight loss. But in spite of this, harm has already been done and the only thing to do is trying to provide against a further increase of the hearing damage.

So a better way to proceed is to take preventive measures, a.o. by performing noise measurements, which may inform us beforehand about a possible traumatical influence of the existent noise on the spot. Therefore one should ascertain which can be the highest intensity of a noise as a function of the frequency that can be tolerated without causing, even after a long exposure, a permanent hearing damage.

DAMAGE RISK CRITERIA FOR NOISE INDUCED HEARING LOSS

In 1952 STERNER held an inquiry among experts into the question which noise levels could still be considered admissible. The answers he received were so strongly divergent that it was obvious that it is not a simple task to determine the exact borderline between injurious and non-injurious noise. Numerous standards of noise tolerance have been published in the course of time. Just as many turned out to be incorrect or incomplete.

Regarding the noise level, attention at first was only paid to the over-all intensity. Having realized, however, that not only the intensity but also the spectral energy distribution of the noise is important, later published damage risk criteria were based on spectral analyses of the noise. In the U.S.A. the D.R.C. designed

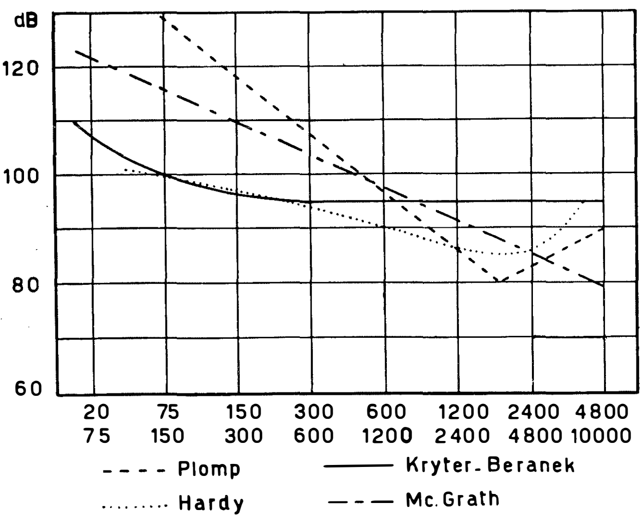

Fig. 5.
Various proposed damage risk criteria for noise.

in this way by KRYTER-BERANEK is much used. (fig. 5). From practice it has appeared, however, that for the ca. 1500-6000 Hz area this criterium is too high. These experiences from practice are in concord with the experimental data and thus do show indeed how much more damage is done by the high frequencies than by the low ones.

MC GRATH's criterium, designed on purely theoretical grounds, takes this fact more into account. Yet it does not prove tenable.

An important criterium is HARDY's, since in practice it has proved to be quite satisfactory.

The foregoing three criteria, although theoretical in design, have all been compared to observations from practice. One may, however, also try to design a criterium according to experimental findings. Such experiments are also based on the phenomenon of the temporary threshold shift. In this case again, one starts from the hypothesis that there exists a relation between the permanent and temporary threshold shift.

In this connection the investigations by a.o. PLOMP in the Netherlands should be mentioned.

By performing a number of exposure tests with various frequency bands at different intensity levels, attempts have been made to determine the levels at which these bands cause similar temporary threshold shifts. In this way so-called *isotraumatical curves* have been drawn up, i.e. lines connecting points which under equal conditions (only the stimulatory frequency band is variable) cause equal threshold level elevations.

The slope of these curves could then be a starting-point for the slope of the noise criterium. It turns out that this slope is most approximate to HARDY's criterium.

After having performed similar tests KYLIN also arrives at this conclusion.

Concluding one may say at the present moment that in practice especially the frequencies near 3000 and 4000 Hz are most detrimental to the auditory organ. The transition between injurious or non-injurious noise levels will be in the 1500-6000 Hz region between 80-90 db. Below 1500 Hz greater intensity may be admitted. It should, however, specially be mentioned that a really reliable damage risk criterium cannot yet be provided.

THE VALUE OF A DAMAGE RISK CRITERIUM

In industry where one is chiefly concerned with preventive and diagnostic measures, one will not be interested so much in a sharp marked borderline between injurious and non-injurious noise but attention will rather be directed to a kind of critical intensity region. Noise at an intensity level which is within this region may have a traumatizing effect and requires constant attention. A noise-intensity below this band is non-injurious whereas it is absolute certain that a noise intensity above this band is indeed detrimental. So in fact the damage risk criterium forms the upper limit of this region. Devising such a region of potential danger is still an ideal, the realization of which will be achieved best by evaluation of large numbers of audiograms taken on employees of which all the necessary data, as character of the noise type, total time of exposure and duration of exposure each time, are known. It has been pointed out already that many difficulties are encountered when gathering such data. After such an investigation one may try to trace the actual relation between the intensity of a noise in different frequency bands, exposure time and detected hearing losses. An important investigation in this manner is the one by the American Committee Z 24 x 2, conducted by ROSENBLITH.

To give a clear impression of the present state of affairs, we do best to cite a recent statement by LIERLE, which goes as follows:

"At the present time our knowledge of the relations of noise exposure to hearing loss is much too limited for us to propose "safe" amounts of noise exposure. This tentative hearing conservation level is stated as follows: If the sound energy of the noise is distributed much or less evenly throughout the eight octave bands and if a person is to be exposed to this noise regularly for many hours a day, five days a week for many years, then if the noise level in either the 300-600 Hz band or the 600-1200 Hz band is 85 db the initiation of noise exposure and control tests of hearing is advisable. The more the octave band level exceeds 85 db the more urgent is the need for hearing conservation."

Noise deafness and social validity

In the Netherlands noise deafness owing to industrial noise is not looked upon as a purely occupational disease in the legal sense. This imports among other things that possible compensation claims put forward by the afflicted person are not paid as a rule. In case one should proceed to the settlement of such a compensation, then this will usually be done not so much on the basis of the total amount of hearing loss as is stated by means of the threshold audiogram but rather on the basis of a loss in social validity.

Expressing the validity of the hearing organ in fixed percentages, however, is a very intricate matter. A great many divergent factors of medical/psychological and medical/ social nature should be taken into account. There is much diversity in the different countries as to the various means of evaluation of disability due to hearing impairment. A general opinion on this question has not been formed up to now (ARSLAN).

The greatest handicap from which the deaf suffer are the difficulties encountered in normal communication by means of speech. Speech hearing, pre-eminently the means of communication, is in modern society a matter of vital importance.

Other handicaps, which may be experienced due to deafness or hardness of hearing, as not being able to hear music, warning sounds etc. are, though important, yet strongly inferior to that one complaint of not being able to follow normal conversational speech under normal conditions. If one should want to simplify the determination of the validity of the auditory organ, the best thing to do is restricting oneself to the investigation of the normal understanding of conversational speech.

Starting from this point of view, methods have been suggested to calculate a validity index according to the pure tone threshold audiogram or the speech audiogram.

The methods based on the threshold audiogram in fact date from the time that speech audiometry had not yet developed properly. The best-known of these methods are undoubtedly those designed by FOWLER, the A.M.A. (BUNCH and SABINE), FLETCHER, FOURNIER and the so-called three average method.

KRUISINGA in his thesis submitted the issues obtained with these different methods, to a critical comparison. He then arrived at the important conclusion that determination of the validity of the hearing organ according to the tone threshold is, in his opinion, unreliable and that on the strength of the following facts:

1. Speech understanding does not take place at threshold level but well above it.
2. The auditory organ has above threshold level characteristics which are not necessarily dependent on the hearing threshold.
3. With the aid of threshold audiometry for pure tones it cannot be considered in how far the patient has compensated in a particular way his speech hearing loss.
4. In these methods the redundancy of speech sounds is not taken into account

Such facts particularly emphasize that speech hearing can only be tested by means of speech. The determination of a validity index should take place on the basis of a speech audiometrical test. Other investigators a.o. QUIST HANSEN and STEEN also arrived at this conclusion demonstrating that these methods in which speech hearing is calculated according to the threshold audiogram yielded unreliable results as well in cases of noise deafness.

The modern way of testing hearing may not be considered complete when the speech audiogram is lacking. It is, therefore, a risky matter to draw conclusions concerning the validity on the basis of the threshold audiogram.

The speech audiometrical tests as they are carried out with P. B. lists are, however, attended with disadvantages as well.

It is true that in that case speech hearing is tested by means of speech but one should not lose sight of the fact that the normal situation under which speech is understood has undergone considerable changes. For it is the *word*-intelligibility which is being tested and not the *sentence*-intelligibility while in normal intercourse it is indeed this sentence-intelligibility with which we are concerned. So it would be more accurate to devise a speech audiometrical test in which no P. B. word lists but P. B. sentence lists are used. Consequently the usual speech audiometry is insufficient for a proper determination of a validity index. This, however, does not alter the fact that it may provide us with very valuable data, such as threshold of speech intelligibility and discrimination loss, indispensable for the determination of validity.

Quoting WALSH and SILVERMAN, nowadays the so-called S. A. I. (Social Adequacy Index), i.e. the average of the three articulation percentages found at 55 db, 70 db and 85 db, is calculated from the speech audiogram, representing the intensity levels of weak, normal and loud voice. Although this S. A. I. is not a right criterium either for the validity, the results of it are yet superior by far to those acquired with calculations according to the threshold audiogram. In practice this S. A. I. is in most cases quite satisfying.

Speech audiometry, however, has another very considerable drawback of more economical nature, namely the long period of time which is required for a complete test. Especially in the industrial hygienic group tests this is felt to be a very important objection.

In many cases it would mean an enormous saving of time when from the threshold audiogram could be inferred whether there is any possible diminished speech intelligibility.

In this connection it is important to investigate whether in case of a specific deafness as noise deafness any relation between threshold loss for pure tones and loss of speech hearing can be indicated.

It also seems desirable to find out which factors favour decrease of speech hearing in noise deafness.

Such an investigation for which purpose i.a. some experiments with filtered speech were performed, will be described in the subsequent chapters of this thesis.

Before entering into this matter, however, it seems essential to devote in the next chapter a few pages to speech hearing under normal and pathological conditions.

Chapter II

NORMAL AND PATHOLOGICAL SPEECH HEARING

Physical properties of normal speech

The smallest units to be distinguished in speech are the speech sounds or phonemes. These phonemes are composed of complex sound vibrations, varying continuously within a certain period of time in intensity and frequency. The differentiation between the phonemes is large, both as regards the average power and the spectral energy distribution. From an investigation by G. F. BLEEKER it becomes apparent i.a. that the difference in energy between the strongest and the weakest speech sounds amounts to 27 db. It also appeared from his investigation that on the average the vowels exceed the voiceless consonants by 12.7 db in loudness. Also in the distribution of the energy along the tone scale large differences are to be seen between vowels and consonants. This holds for the Dutch language. Several consonants have an almost continuous noise spectre with frequently the greatest energy in the higher part of the tone scale. In case of vowels, on the other hand, distinct peaks (formants) may again and again be seen in the spectral energy distribution; they consist of a series of pure tones with a constant frequency distance.

Normal speech hearing

For a proper understanding of the normal speech hearing function, two concepts should be distinguished well:

1. The speech hearing threshold.
2. The discrimination capacity.

Ad. 1. The speech hearing threshold represents i.a. the sensitivity of the auditory organ. This sensitivity depends on the level of the threshold curve all along the tone scale. So in this respect we may speak of a *liminal* function.

Ad. 2. The discriminative ability, on the other hand, is a *supra-liminal* function of the auditory organ and comprises two concepts:

a. The speech intelligibility;
b. The speech hearing capacity.

Ad. a. SPEECH INTELLIGIBILITY

In speech three physical factors - *intensity, frequency* and *time* - can be distinguished which are important for a good speech intelligibility. Any disturbance in the interplay of these three factors may influence the intelligibility. We will confine us here to the first two factors.

By the physical sound pattern which is connected with speech, the peripheral auditory organ is stimulated. After a certain pre-analysis which enables the peripheral hearing organ among other things to perceive differences in intensity and frequency (differential threshold for intensity, resp. frequency) this stimulus is transmitted via the nervous pathways to the cerebrum, at first only to be registered there in its components and afterwards to be integrated and identified as a comprehensible sound pattern.

So it may be said that the function of speech hearing is i.a. to connect a certain physical vibratory process with a memory pattern, in this case a sound pattern, which has gradually developed by frequent repetition in our consciousness.

Ad. b. SPEECH HEARING CAPACITY

Besides this speech intelligibility a cerebral function may be distinguished viz. the speech hearing capacity. The latter could be defined as the skill or the ease with which in the cerebrum, by means of the nervous impulses issued by the peripheral hearing organ, the awareness of hearing arises.

This speech hearing capacity differs individually. It is not clear by which this capacity is determined but it is certain that factors as intelligence, association and concentration-span play an important part in it. Is is also a well-known fact that this skill by practice may be enhanced, a clinical application being modern auditory training. Remarkable is also the extraordinary skill which especially in case of noise deafness may develop rather rapidly. In contrast with what the threshold audiograms would make one expect, speech hearing will remain remarkably well.

Some important conclusions may be drawn from this:
1. It is possible for the deaf ear to reach in some cases a good speech hearing capacity without the formants performing their usual function. The bass frequencies appear to play a much more considerable rôle in these cases than is the case with normally hearing persons.
2. The speech hearing capacity in these seriously hard of hearing cases may be reached after conscious or unconscious auditory training and strongly depends on intelligence and other mental factors.
3. In cases of slowly acquired deafness, as e.g. noise deafness, there is a gradual adaptation, taking place unconsciously.

From the above-mentioned it becomes apparent that for a correct interpretation of sound impulses it is necessary to have:
1. A normal threshold along the entire tone scale;
2. A normal differential frequency threshold;
3. A normal differential intensity threshold;
4. A good cerebral function;
5. A certain speech hearing capacity.

Conclusively we may say that speech hearing is based on past experience gained under the influence of physical quantities and physiological functions.

Pathological speech hearing

A hearing loss resulting from a deficient speech hearing function can, roughly spoken, always be reduced to the following causes:
1. Decreased sensitivity of the auditory organ;
2. Loss of discrimination capacity.

In case of *conduction deafness* there is only a decrease in sensitivity. The insufficient loudness of the speech sounds leads to an increase of the speech hearing threshold. The discriminative capacity remains, in the beginning at least, undisturbed so that the speech hearing function can be fully restored by an increase of the speech intensity in about the same degree as the average hearing loss along the tone scale according to the threshold audiogram.

In case of *perception deafness,* matters are much more complicated. Besides an increase of the speech hearing threshold we are confronted here with pathological factors above the hearing threshold as well, which consequently result in a discrimination capacity loss. This loss in discriminative capacity may be caused by:

a. *Decreased speech hearing capacity.* Such disturbances are often seen in presbyacusis. Most authors (FOURNIER, BOCCA) agree that in this case it is a matter of a delayed cerebral reaction capacity by which in case of older people the time needed centrally for identification, is prolonged. Therefore improved speech hearing is often found in older people when spoken to more slowly.

b. *Decreased intelligibility* of the speech stimuli presented by the nervous pathways to the cerebrum. For this decrease in intelligibility two main causes may be mentioned:

1. A slight peripheral differentiation of the speech patterns;
2. Unusual sound patterns modified by distortions.

Ad. 1. Threshold increases in a limited part of the tone scale as with dips and abrupt threshold audiograms (usually to be seen in the treble part) involve an entire or partial elimination of perception of those phonemes which possess their most important characteristics in that area. So we can say that an incompleteness of the characteristic sound patterns, belonging to normal speech, has come into being.

The perception of the weak voiceless consonants which are most significant for the intelligibility of the whole, will be disturbed first by the selective threshold increases while in case of greater losses in the treble part the perception of the other consonants is disturbed as well.

Ad. 2. The subjective distortion meant here, originates from a pathological function of the inner ear. The speech sounds modified by distortion lead to a hampered discrimination, because the stimuli presented to the cerebrum cannot be recognized as a comprehensible sound pattern.

As principal causes of subjective distortion may be mentioned:

1. ABNORMAL LOUDNESS FUNCTION

This important phenomenon described in 1928 for the first time bij FOWLER SR. and called recruitment, is seen to occur in different forms of perception deafness. Recruitment or regression points as a rule to cochlear disturbance. What is meant by this concept is an abnormally fast increase of the loudness perception after having passed the auditory threshold. Thus with pathological ears a normal loudness sensation is often found at high intensities, whereas at somewhat lower intensities the loudness sensation is often in a considerable degree too low.

HUIZING has been one of the first to point out the significant influence which it exerts upon speech hearing. Important factors for this are:

a. The decrease of the speech hearing threshold or, in better terms, the reduction of the speech hearing threshold increase. So in this case the hearing loss is compensated to a certain extent by the regression phenomenon.
b. Reduction of the hearing-span.
   In case of a hearing loss with recruitment, the difference between auditory threshold and pain threshold will be only slight.
   So supraliminal hearing cannot but occur in a much smaller auditory area which will not favour the intelligibility.
c. Disturbance of the interrelations of loudness within the different speech patterns.
   In case of deafness with recruitment the strongest speech components will be perceived with almost entirely or entirely normal loudness. The weaker components will not or hardly pass the threshold. The disturbance, thus evolved, of the normal loudness relations within the different speech patterns may cause a serious distortion then, hampering discrimination.

Summarizing is may be said that in general recruitment influences speech intelligibility unfavourably. Most authors, however, hold the view that in cases of deafness of less than 40 db, recruitment may still act favourably upon speech hearing.

2. DIPLACUSIS

Diplacusis is a well-known anomaly originating from defective pitch perception in one ear. This involves a disharmonic sequence of speech components which hampers the discrimination.

3. SLOPING TYPE OF AUDITORY THRESHOLD

The importance of the way in which the sloping type of threshold audiogram may influence speech hearing, TASELAAR has recently drawn attention to. Speech intelligibility and speech intensity are linked up with different frequency areas, the former with the high tone region, the latter with the low tone area. In many types of perception deafness a loss is found in the treble part, retaining hearing in the bass region. Consequently there will arise a disturbance of the *spectral energy balance* which exists between the speech intensity, respectively connected with the bass part and the treble part of the tone scale.

By the relatively stronger bass part components a masking of the attenuated treble components is brought about, resulting in a diminished intelligibility.

All the above-mentioned factors which may cause a decreased discrimination capacity are thus either the result of a diminished *cerebral function* (speech hearing capacity) or of a diminished *function of the peripheral hearing organ.*

There still remain, however, a number of primary central disturbances which may lead to a reduction of speech hearing. Of them we mention:

1. PATHOLOGICAL ANATOMICAL CHANGES IN CEREBRO

Tumors, bleedings etc. are able to cause disturbances in the corresponding brain centres, important for speech understanding, which are attended with a loss of discriminative capacity. Lesions of the N. VIII may also cause such disturbances. In this respect SCHUKNECHT a.o. has found in these patients larger discrimination losses than in patients with the same hearing losses of other etiological nature.

BOCCA and MATZKER a.o. have, on the basis of these phenomena, developed methods with which, by means of speech audiometrical examination, the diagnostics of these cerebral aberrations seem possible.

2. PSYCHOGENIC DEAFNESS

The special central disturbances which underlie the discriminative losses, originating in this way, will not be discussed here. They should, however, be taken into account e.g. in cases of simulation and aggravation which sometimes occur with noise deafness too.

Testing the speech hearing function

Speech understanding is linked up with intensity levels well above the auditory threshold. That is the reason i.a. why one had better not draw too important a conclusion, with regard to speech hearing, from the results obtained by means of the threshold audiogram.

All too often there is only a partial agreement between threshold audiogram and the diminished speech hearing which might be expected according to this threshold audiogram. Tone threshold audiometry, therefore, is best to be considered an *organ test,* viz. of the acoustic organ: the ear.

Speech hearing has to be tested by means of speech. This is, for that matter, nothing new, for in 1897 already BEZOLD concluded: „Als regulären und zu einer raschen Übersicht führenden Hörmesser besitzen wir keiner vollkommener als die Sprache".

In the preceding chapter it was discussed in detail, however, how little accurate the results of the usual whisper and conversation speech test are. These testing methods are even now looked upon as having gone out of date and have been replaced in general by a much more exact testing method, viz. speech audiometry at which the so-called P. B.-lists are used. Speech audiometry may be regarded as a *function-test,* viz. a test after the speech hearing function. With this speech audiometrical test in *quantitative* sense, attention is principally paid to the global word understanding. Considering this, one has become conscious of the fact that for recognizing a word not the same value can be attached to each phoneme. Often some characteristic phonemes are of importance only, i.e. those phonemes which are essential for the correct understanding of a word. As long as such a characteristic phoneme (or phonemes) can be recognized well, a word will be understood.

On account of this particularity another form of speech audiometry developed the last few years, viz. the so-called *qualitative* speech audiometry. In this case attention was mainly directed to the discrimination of speech sounds separately and even more to the discrimination of combinations of speech sounds of which the spectral main weight is laid in a selective part of the tone scale. From tests by FRENCH & STEINBERG a.o. it has appeared that normal speech is characterized by a considerable redundancy of informative elements. They studied for this purpose the influence of High Pass and Low Pass filtering on the intelligibility of nonsense syllables. By filtering speech certain components are to a greater or less extent attenuated. This depends on the frequency characteristic of the filter in use. The steeper the curve of this frequency characteristic, the more components are attenuated outside the filtering area. When of speech all components below 1000 Hz are passed on unattenuated, intelligibility will be retained; also when only components are passed on which are above 2000 Hz. When, however, the intelligibility of i.a. P. B.-words in octave bands is observed, this intelligibility appears to have been retained best in bands in the 1000-3000 Hz area. Such results state that in case of normal speech there must be a very large redundancy of informations, at least under normal conditions.

When investigating the discrimination of the separate speech sounds KRUISINGA and LAFON a.o. started from the phonemic exchange occurring in certain cases of perception deafness. The issue of such an investigation, however, did not seem to be in agreement with what might be expected according to the falling out of the formant areas when cutting off certain parts of the tone scale. The characteristic factors for the intelligibility of speech are apparently hard to be judged from the separate phonemes. The combinations of speech sounds, as they are found in spoken context, should be looked upon as a whole.

GUBERINA c.s. evolved a method which they called the *verbotonal audiometry*. They checked the intelligibility of certain words in very narrow frequency bands. To each word, dependent on the phonemic structure of that word, belonged a band of optimal intelligibility, i.e. to normally hearing persons such a word appears to be easily understandable only in this band of optimal intelligibility. In case of pathological ears the sounds which are produced by these "narrow band words" serve to determine the tonal threshold (tonal part) while supraliminally the intelligibility is ascertained (verbal part). The drawback of this method, however, is that these bands are narrow to such an extent that they prove to be hardly of practical value for testing material. Consequently it seems better to start from broader frequency bands in which the tonal part is dropped. On this principle is founded the so-called *Triplet-audiometry* developed by HUIZING c.s. In this case the tone scale is divided into three zones, called, analogous to ZWAARDEMAKER: *"Zona Gravis, Media and Acuta"*. The great redundancy of which normal speech disposes, makes it possible to compile a number of easy words or a number of sentences which under favourable conditions still retain their intelligibility in one of the three narrow bands.

This division of the tone scale into three parts with retained intelligibility in each of the bands presents the possibility to gain an insight into the *partial* discrimination capacity of a hard of hearing patient. The results of this triplet audiometry are interesting and point out to us among other things that, dependent on type and duration of the hearing deterioration, the main weight of the discrimination capacity may have shifted to a specific part of the tone scale. The discrimination capacity appears to be retained best in those parts of the tone scale where the hearing loss, corresponding to the threshold loss, is slightest, i.e. there where the stimuli have remained to be strongest and most frequent.

Thus qualitative speech audiometry proves to be in some cases a valuable completion of the well-known methods for a judgment of the speech hearing function in cases of perception deafness. The data which can be gathered in this way may be valuable for the determination of social validity.

Chapter III

THE CURRENT INVESTIGATION

Introduction

The outcome of speech audiometrical tests, performed in cases of noise deafness, indicates that this type of hearing loss may often lead to discrimination losses. In the preceding chapter we have dwelt upon the causes of discrimination losses in perception deafness. The most important causative factors possibly playing a part in noise deafness, will be briefly summarized once more.

a. Incompleteness of the normal speech sounds.
b. Disturbance of the spectral energy balance.
c. Recruitment.
d. Decrease of speech understanding capacity.

Little do we know, however, about the degree in which each of these factors may contribute to discrimination loss.

In the foregoing chapter we also mentioned the great redundancy which characterizes normal speech. As a result of this, the bandwidth of speech may be shortened considerably, without, under favourable conditions, leading to a subjective decrease of speech understanding. From experiments carried out with electric octave band filters it has appeared that the frequencies in the middle and lower treble part of the tone-scale (1120-2240 and 1600-3200 Hz) give the highest contribution by far to intelligibility.

At the initial stage of noise deafness there will be a hearing loss in the higher treble part of the tone-scale. The more the hearing loss expands to the frequencies from the above-mentioned octaves, the more seriously will speech intelligibility subjectively be disturbed. Considering the minute informative value speech components in the higher descant part of the tone-scale possess, no subjective decrease of speech hearing in initiating noise deafness is, accordingly, to be expected.

Filters may be highly valuable for studying speech hearing. For, in a way, one is able to imitate different types of deafness by means of these apparatus. In case one should, from a purely theoretical point of view, consider the noise-induced hearing loss as having resulted from filtering - the cochlea serving as a filter - then in fact it must be possible to correct this hearing loss by selective amplification of those frequencies which are perceived inadequately. When such an amplification is needed for restoring a possibly diminished *speech intelligibility,* then it does not seem necessary to apply this selective amplification to the whole part of the tone-scale in which a hearing loss is present. In that case one may restrict oneself to some part of it and that in such a way that the offered speech will again comprise sufficient informative elements to be understood properly. When such an amplification is used for cases of perception deafness, the significant causes of distortion of speech sounds should also be taken into account. For the interest of speech intelligibility, amplification should be such that the occurrence of subjective distortion at least, does not increase by it and if possible is eliminated.

So the amplification of speech sounds must be selective indeed and not uniform all over the tone-scale. Selective amplification may thus be helpful when decrease of speech hearing is the result i.a. of a disturbance of the spectral energy balance (bass-part/treble-part).

Greater problems may be encountered, however, when distortion is also caused by recruitment since the needed amplification for the various components of a speech sound may be strongly different in case of a pathological loudness function. Not much value should be attached, however, to the subjective distortion brought about by recruitment when this recruitment is confined to those frequencies, which contribute no essentially informative elements to intelligibility. So this concerns the frequencies near 4000 Hz.

Besides a possible disturbance of the intelligibility of speech, distorted by noise deafness, when presented to the cerebrum, in the cerebrum itself there may be a deficiency of speech hearing capacity as well. It will not do to assume without further investigation that this speech hearing capacity will remain normal. This is proved among other things by the results acquired with triplet audiometry and performed in various kinds of deafness. Partial discrimination losses in those parts of the tone-scale in which the hearing threshold loss is largest, appear to be of frequent occurrence. Such partial discrimination losses may particularly be expected in long-standing hearing losses. Thus in noise deafness this will often be the case with elderly people. Here we are confronted with the difficulty, however, that in case of persons well on in years, we cannot speak of pure noise induced hearing losses, but also of presbyacusis. A diminished speech hearing capacity occurring at an advanced age may just as well be the result of this presbyacusis with which noise deafness has nothing to do.

In connection with what has been said before of the selective amplification which has to improve speech intelligibility, the question arises in which frequency band such an amplification is necessary in order to eliminate in this way any decrease of speech hearing. To this end one should know at which threshold loss, owing to the noise trauma, one may begin to speak of a diminished speech intelligibility. With the usual speech audiometric tests the *word*-intelligibility is chiefly tested, which, as a matter of fact is a different thing than *sentence*-intelligibility. So actually we should ask ourselves: "When does a decreased word-intelligibility arise?"

First perception of the weak high-pitched speech sounds will be disturbed as a result of a noise trauma. When the composition of a certain word will be such that it contains one or more characteristic high-pitched phonemes, as s, f, t, ie, etc. (characteristic phonemes, see chapter II) then such a word will be misunderstood first. These typical high-pitched words are only occasionally met with in normal conversational speech but still in case of misunderstanding of these words we cannot speak any longer of undisturbed speech hearing.

For tracing these slight disturbances in speech understanding capacity, the normal speech audiometric tests with the help of P. B. lists are insufficient. It is true that these wordlists are phonetically balanced, but in composing the words one has not reckoned with the spectral character of the words. Seeing that it is indeed the spectral composition of the words with which we are concerned here, we will have to use another way of speech audiometric testing, namely the *qualitative* speech audiometry. For with this testing method the main purpose is the examination of discrimination of groups of speech sounds of which the spectral composition is predominating in a pre-determined part of the tone scale. In the present case we are concerned with the discrimination of typically high speech sounds, the main weight being laid in the high discant part of the tone-scale.

Scope of the investigation

For a good judgment of speech hearing in noise deafness, it is highly important to realise the factors which may lead to discrimination losses in this type of deafness. In order to augment our knowledge in this respect, it seemed useful to us to perform a speech audiometric investigation in a qualitative sense. This was also done with a view to the question whether elimination of decrease of speech hearing is possible by means of selective amplification.

For carrying out these experiments we had the disposal of extensive filter apparatus which were gratefully used.

A special kind of speech was developed by filtering normal speech in a way which will be described subsequently. Though characterized by a markedly high-pitched quality, this special type of speech is, under favourable conditions, still comprehensible to normal hearing persons. The manner of filtering has been chosen in such a way that the low frequencies in this speech sample are lacking while the main weight of the spectral energy, as far as intelligibility will admit, lies in the high frequency area near 4000 Hz. The frequency response area in this case of filtering has been chosen in such a way that it almost mirrors the dip in the tone threshold audiogram which is so characteristic of noise deafness. In continuation of ZWAARDEMAKER's terminology, we called this specific kind of speech, *peracute speech.*

In order to increase the margin of intelligibility of this peracute speech, the test words were composed from selected phoneme material. In this way one has aimed at bringing the most characteristic frequencies of these phonemes as much as possible within the filtering area. So in peracute speech mainly high-pitched phonemes such as *s, f, t, ie,* etc. will be found.

The way in which this peracute speech was obtained by means of filtering will be described in this chapter. The acquired speech sample will also be submitted to an examination concerning its spectral energy distribution.

Once a filtered word list, adequate to audiometric testing has been procured, in a following chapter we will describe:

a. Speech audiometric testing with peracute speech of normal hearing individuals, therewith investigating intelligibility as a function of intensity.
b. Speech audiometric testing with peracute speech performed in case of noise deafness, therewith investigating in how far discrimination of the high speech sounds was possible by these hearing handicapped persons.
c. A closer study of the results of the investigation, as well as a discussion of possible conclusions to be drawn from it.

Experiments for obtaining peracute speech

The so-called peracute speech, as has been mentioned, was obtained by using variable filters. A primary requirement for this special speech sample is the preservation of intelligibility to normally hearing persons.

A discussion will follow of the technics of filtering and recording in order to obtain that type of speech, adequate to carry out the qualitative speech audiometric tests in persons with normal hearing and cases of noise-induced hearing loss, as has been described in the preceding section. The apparatus used in these experiments will also be mentioned. The various experimental arrangements will be reproduced in block schemes.

I. *Filter characteristics*

In order to have peracute speech deprived of low frequencies as much as possible, we aimed at using such a High Pass filter combination that its cut-off frequency, as far as preservation of intelligibility would admit, got as near as possible to 2000 Hz. It was also important that the slope of the frequency response characteristic (or filter characteristic) ran as steep as possible so that in this way an optimal attenuation of the low frequencies could be reached. The energy was optimally passed round about 4000 Hz.

Applying so-called variable filters, a Frequency Response Tracer as made by the firm of Bruel & Kjaer turned out to be of much value. By means of such an apparatus the filter characteristic which comes into being after connecting some variable filters in series can be read off immediately on the fluorescence screen of this apparatus. This procedure saves much time and elaborate measurements, since any frequency response adjustment may be controlled on the screen.

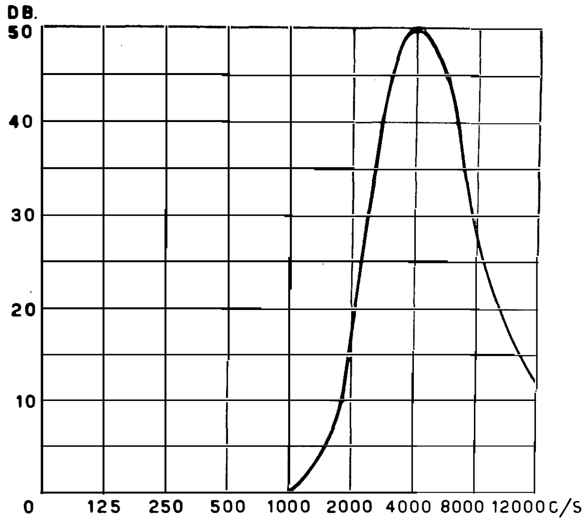

Fig. 6.
Filter-characteristic used for processing peracute speech.

By connecting a number of filters in series (see block scheme I) a filter characteristic was obtained which seemed to meet requirements (see fig. 6). The apparatus necessary herewith consisted of:

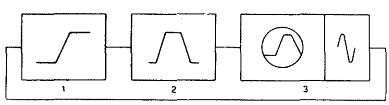

Fig. 7.
BLOCK SCHEME I. (see text)

1. So-called audio effects filter type 37 A made by The Daven Company.* This apparatus consists of a number of High Pass and Low Pass filters with a large number of cut-off frequencies. The cutting-off can be adjusted to six different filter qualities. Therefore the steepness of cutting-off may vary from about 10 to 20 db/octave.

* This filter was kindly put at our disposal by the Health Organisation T.N.O.

A High Pass filter was used: cut-off frequency 2500 Hz. Steepness over 20 db/octave.

2. Octave-band pass filter type OB-5 from the firm of Wandell and Goltermann. The frequency response area covers eight successive octaves, starting at 35 Hz up to 9200 Hz or from 50 Hz up to 12.000 Hz. From these, every time one single octave, at choice, may be passed. The steepness amounts to 15 db/octave. The octave 3280 up to 6400 Hz was passed.

3. Frequency Response Tracer type 4708 from the firm of Bruel & Kjaer.*. By means of this instrument one is able to check, in a convenient and rapid way, large numbers of microphones, loudspeakers, amplifiers and filters etc. on their frequency characteristic. The latter is made visible on a cathode-ray-tube with a long afterglow. The abscis has a logarithmic intensity scale with a range of 50 db.

Starting from this filter characteristic, attempts were made to filter and record on tape a number of words which still remained comprehensible to normal hearing persons.

II. *Recording-technics*

A list, comprising several short sentences, as well as some easy words was composed. These were spoken into a microphone then, all as much as possible with equal effort at a specific sound intensity level. After passage of filters and amplifiers it was recorded on tape. Foı the apparatus used, be referred to blockscheme II (fig. 8).

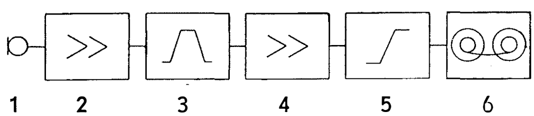

Fig. 8.

BLOCK SCHEME II

1. Dynamic microphone (Philips type El 6020),
2. Amplifier,
3. Filters: Daven Company / W. & G., } (see above),
4. Intermediate amplifier, (General Radio type 1206 B),
5. Filter, type Multiper H. P. 1000 Hz.,
   This filter served for filtering out an interfering hum having originated in the apparatuses.
6. Bandrecorder (Revox) model C-36.

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* We could make use of this apparatus thanks to a financial gift from the HEINSIUS-HOUBOLT Fund.

III. *Sound reproduction*

The result of filtering and recording which, eventually, was heard throught the loudspeakers, turned out to be subjective unpleasant and sharp with a markedly high tone character. For the process of this sound reproduction be referred to blockscheme III (fig. 9).

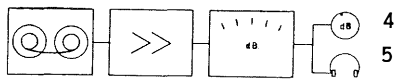


Fig. 9.

BLOCK SCHEME III

1. Bandrecorder (Philips type El 3538 A),
2. Amplifier,
3. Decibel attenuator,
4. V. U.-meter,
5. Head phone set.

Besides the signal, i.e. the peracute speech, a considerable background noise was audible having originated in the various amplifiers included in the circuit. We will refer in this chapter again to the significant influence this noise exerts on intelligibility.

To those, familiar with the spoken text, some words or sentences proved to have been mutilated to totally unrecognizable sounds. Therefore, the same recording procedure was carried out once more, the unrecognizable words being left out.

Intelligibility in case of normal hearing test persons

The peracute speech, acquired in the way as has been described above, was offered to a number of test persons unfamiliar with the contents.

Test persons were a number of male medical students, all of them having normal hearing thresholds. The text was listened at for some consecutive times at an intensity level which the test persons found to be most comfortable. As regards intelligibility, the following could now be noticed:

1. ca. 15 words of the total list can be understood well, each time at an almost equal intensity level. Irregular intelligibility was found for the remaining words.
2. The short sentences appeared to be irregularly understandable.

At first the latter statement seems strange. For it is a well-known fact that, as a rule, sentence-intelligibility will be better indeed than word-intelligibility. This is undoubtedly linked op with association factors. Not only does the acoustic spectre of the words determine intelligibility, but also that which the listener *expects* to hear. The guessfactor may favour intelligibility of words comprised in short sentences. When composing peracute word lists, however, we had to reckon with the fact that as much as possible high-pitched phonemes should be employed. Now this considerably limits the vocabulary to be used. Consequently in the compilation of short sentences some interjections and connective words would inevitably creep in which, owing to their phonemic structure, could hardly be considered for peracute speech. Only the few key-words in the sentences remained fully intelligible.

On account of this outcome it seemed better to omit the sentences for further speech audiometric tests.

3. Another striking fact was that intelligibility improved when the listener was given an opportunity to get used to the somewhat unfamiliar sounds he would have to listen to. Therefore it was thought desirable to let a "carrier phrase" precede the word list. Indeed results appeared to be more constant then, as far as intelligibility is concerned, and so more reliable as well. Also in triplet audiometry one has gained similar experiences.

vier	instituut
zes	ziek
incident	schrik
stiefzuster	zweefvlieger
twistziek	diepzeevis
visite	kerstfeest
minister	systeem
kersvers	

Fig. 10.
PERACUTE WORDLIST

In this way we finally disposed of a list of 15 words with which in the usual manner, articulation measurements could be performed.

By means of a db-attenuator (see block scheme III) signal and noise together can be offered to the listener at every desired intensity (in steps of 5 db). It is important to remark that the S/N ratio remains constant all the time. Further it should be mentioned that at high intensities intelligibility might decrease as a result of objective distortion. So in order to arrive at comparable and reliable results, we are committed to a certain range i.e. the usable intensity span at which speech can be presented, is limited.

Viewing the peracute word-list as reproduced in fig. 10, it will be somewhat astonishing to find that it strongly deviates, as regards composition and contents, from normal word-lists which are, as a rule, used in speech audiometric tests (e.g. Spondae-lists and P. B.-lists). One should take into account, however, that in this case we are just concerned with some arbitrary words. In spite of their mutilated structure, due to filtering, they do offer so much information that intelligibility still remains possible. So here we have to do with words with a great spectral conformity as a result of their specific phonemic structure and their selective filtering.

Analysis of signal and noise by means of $^1/_3$ octave filters

Before performing with the obtained word-list speech audiometric tests, in cases of normal hearing and noise deafness, it seemed to be of primary importance to gather some more exact data concerning the S/N ratios occurring at the various frequencies. This with the intention of obtaining a clearer picture about the spectral energy distribution of the physical sound patterns belonging to the peracute words as they will be presented to the listener with various intensities. It is true that the sound patterns belonging to each word show mutual differences, but considering the conditions under which these sound patterns have come into being, we may assume that these differences are not large.

For this purpose the words were filtered once more, this time by means of a number of filters which are included in the so-called audio frequency spectrometer (type 2109) made by the firm of Bruel and Kjaer.* This apparatus comprises, among other things, 27 filters, the central frequencies of which lying at a distance of $^1/_3$ octave from each other along the tone-scale. By means of this series of filters the tone-scale may be split up into a number of small frequency bands, each of $^1/_3$ octave width. On a meter, calibrated

* We could make use of this apparatus thanks to a financial gift from the HEINSIUS-HOUBOLT Fund.

in db, coupled to the filter, it is now possible to read off separately the energy of the noise and approximately also the peak values of the signal, which in each of these narrow bands is passed. With these measurements the peak values in every word appeared to differ from each other but these differences were never large (ca. 3 db). Therefore for each frequency band the average of the measured peak values was determined. These measurements were carried out in this way in 15 different narrow bands (250-8000 Hz). The results represent the S/N ratio in each of these bands.

Proceeding in this manner, it was finally possible to form an impression as to the spectral outline of the sound pattern in the tone-scale, as well as of the energy ratios existing between noise and signal within the sound pattern.

The measured data have been laid down in fig. 11, the central frequencies having been plotted out on the abscis, the measured energy of noise and signal in each of these bands on the ordinate. From this figure, the results of which were found at an arbitrarily adjusted intensity level, it becomes apparent that there exists a noise that is first measurable in the 640 Hz. band. In the subsequent bands with higher central frequencies the noise intensity increases, attaining an optimal value in the 1000 Hz band. This maximal noise intensity is retained in the successive bands within which measurements were carried out. As to the real signal, so the actual speech, no energy is measured in the bands below 1600 Hz. Besides the fact that in these bands no signal was measurable, speech was not audible either, when listened to. Consequently, it does not seem likely that the spectral part of the sound pattern which lies below 1600 Hz will contribute any information as regards intelligibility of peracute speech. It becomes apparent, further, that in the 1600 Hz band for the first time a somewhat stronger signal intensity than the noise intensity is measurable. In the consecutive higher bands the value of this signal intensity rapidly increases, reaching a maximal value in the 3200 Hz band. In the bands above the 3200 Hz band the signal intensity decreases again.

Thus in the bands with 1600, 2000, 2500, 3200, 4000 and 5000 Hz as central frequency, the S/N ratios amount to resp. 5, 15, 25, 35, 30 and 25 db.

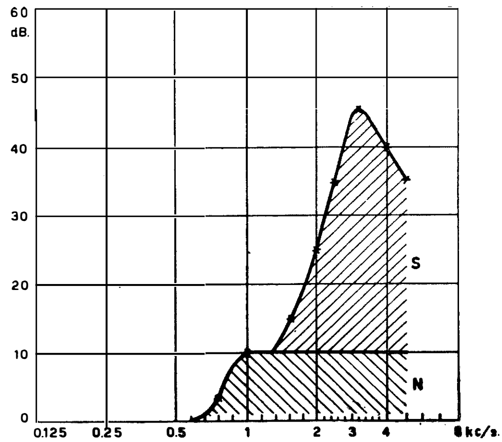


Fig. 11.
Peracute sound intensity-pattern at an intensity level of 45 db.
S = Signal. N = Noise.

In the determination of articulation scores with the help of peracute speech, a sound pattern with various intensities, increasing in steps of 5 db, is presented to the listener. This sound pattern has been made up out of a signal and a noise part, the signal having to provide for the information necessary to recognize the proffered sound patterns as comprehensible.

It is important to mention that with each intensity at which the sound pattern is presented, the above-outlined S/N ratios, existing within this sound pattern, remain constant all the time.

To be able to express in db the over-all intensity at which peracute speech is offered, it will be defined henceforth as the intensity which is measured in the 3200 Hz band since this is the band in which for all words the greatest intensity is measured. This intensity as indicated in fig. 11, then amounts to 45 db.* In that case the actual signal intensity is, accordingly, 45 db, the noise intensity 10 db. Should the peracute speech be presented with e.g. 45 db, this means that in that case only the signal part is offered above the listener's hearing threshold.

From the aforesaid it is obvious indeed that the title *"peracute speech"* has been rightly chosen. The spectral energy of this speech sample is almost exclusively concentrated in the high tone region.

* Re = 10^{-16} Watt/cm^2.

The audible speech components in the central octave (1000-2000 Hz) only supply a minute energy contribution which, possibly, is indispensable yet for intelligibility. So it is easily understood that peracute speech has a markedly high and sharp sound character.

It has appeared already that this type of speech still comprises sufficient informative elements to be understood by normal hearing persons. For the greater part this intelligibility is the result of the favourable phonemic structure of the words which were filtered in the above-described manner.

Chapter IV

SPEECH AUDIOMETRICAL TESTS WITH PERACUTE SPEECH

A. Normal hearing test persons

As usually in common quantitative speech audiometry, the percentage of properly understood words (articulation score) can be plotted out in an articulation curve as function of the intensity. (see fig. 2, ch. I) For that purpose articulation scores should be determined by presenting speech in the form of e.g. P.B.-lists at various intensities, either binaurally or monaurally. The foot of the curve, i.e. the point at which the easiest word is understood first, is usually called speech hearing threshold. For the determination of such an articulation curve with peracute speech we, naturally, did not dispose of different P.B.-lists, but, on the contrary, of one word list only consisting of fifteen words. In order to draw up a reliable curve all the same, with the rather limited number of test words we had at our disposal ,the list was presented to every test person three or four times, each time at a different intensity. We started with a low intensity at which a single word only could be understood. In this way we avoided the possibility that when presenting the list the very first time at such an intensity that it could be fully understood, it would be worthless for the determination of other points of the curve. For in that case the listener would have become familiar with the contents of the short peracute wordlist. This procedure proved to be quite satisfactory in practice and gave no occasion to doubt the reliability of the test results found in this way.

Because from practice it had appeared that after a certain adaptation to the sound intelligibility improved, preceding to the definite word list a short text sample was offered which had been processed in the same way. The test person was given an opportunity to listen to this piece of text at an intensity level at which in his opinion, the words were easiest to understand.

The speech perception threshold having been established, repeated presentation of the entire word list followed. With each repetition intensity was increased by 5 db. The articulation score, i.e. the number of properly understood words, was taken down at each intensity level. Finally the test person himself was asked to indicate the intensity level at which the words could be understood easily and without effort. This intensity level might be compared to the "most comfortable level" which refers to the listening to normal speech.

Proceeding in this way articulation scores were determined for 20 persons, their threshold audiograms showing no larger deviations than 5 db as compared to the average normal threshold in any part of the tone scale. Each time the test was performed monaurally and in a sound-treated room.

Results of the investigation

The articulation curve, composed out of the individual test results, is laid down in fig. 12. It turned out to be no easy task to determine a speech perception threshold during the test. Nevertheless, it could be ascertained that, when presenting the sound stimulus at an intensity of 15 db, all persons were able to recognize it as speech. Moreover, it became apparent during the test that the individual articulation scores diverge rather strongly when presenting it with intensities (in steps of 5 db) beyond this perception threshold. According as speech is offered with greater intensity, however, the spread of the articulation scores decreases. Obtaining such strongly divergent articulation scores at the presentation of relatively low intensities cannot be called a specific quality related to peracute speech. For similar large divergences are also found in the determination of articulation scores with the aid of P.B.-lists.

It also appeared to be difficult to determine with this word list the foot of the articulation curve. Thus, presenting it at an intensity of 25 db only one person appeared to be able to understand one word. Presenting the word list at an intensity of 30 db, on the other hand, articulation scores already varied from 0 to 10 properly understood words. The maximal articulation score was attained by all persons when presenting at an intensity of 45 db. The most com-

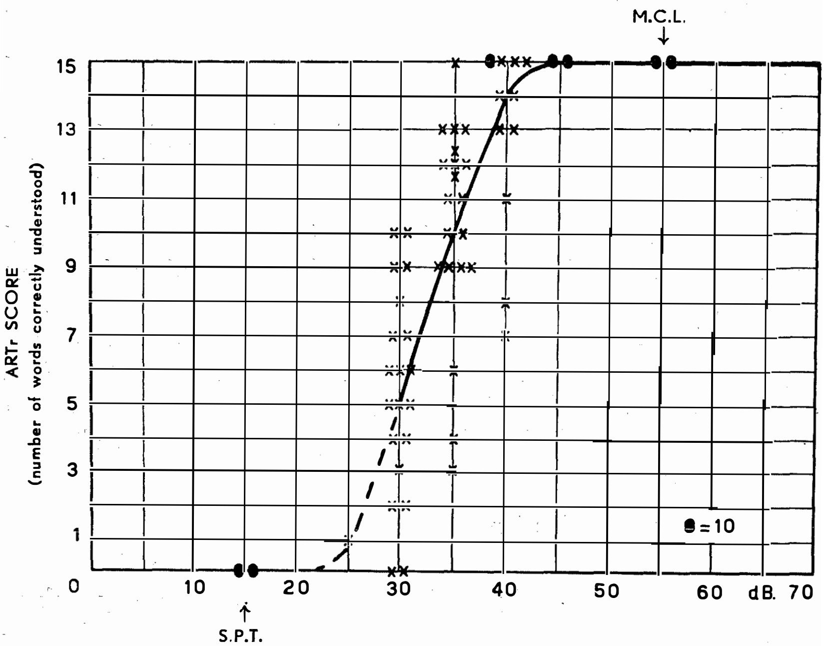


Fig. 12.
Articulation curve for peracute speech determined on twenty normal hearing persons.

fortable level was attained at 55 db. It was striking that even when presenting at 90 db, a maximal articulation score could still be obtained.

So the above-mentioned results again point out that peracute speech still comprises sufficient informative elements to constitute a sound pattern which can be recognized centrally.

Although in case of this highly mutilated speech we certainly cannot speak of a great redundancy of informative elements, as is the case with normal speech, it remains to be seen whether, regarding this peracute speech, we may not have to do with some degree of redundancy either. Should this be the case indeed, then intelligibility would also be possible in cases where only part of the sound pattern belonging to peracute speech is presented beyond hearing threshold. Such incomplete peracute speech sounds will be presented e.g. in case of a threshold loss in that region of the tone scale in which the audible part of the signal possesses spectral components.

Similar selective threshold level increases are found i.a. in noise deafness. The outcome of speech audiometrical tests with peracute speech, performed in persons afflicted by noise deafness, will yield further data with respect to the conditions under which this speech sample is understandable. We will refer to this again.

Finally, concerning the articulation curve for normal hearing persons, it should be mentioned that the whole process of reaching full intelligibility from 0 to 100 % takes place within an area of 20 db. So this means that the articulation curve for this peracute speech will have a somewhat steeper slope than the articulation curves which apply to normal unfiltered P.B.-lists.

B. Test persons with pathological hearing

When it had become clear from the foregoing under which conditions normal hearing individuals are able to understand peracute speech, the next thing to be done was to ascertain in how far and under which conditions this kind of speech can be understood by persons suffering from noise deafness.

Since in this type of hardness of hearing a threshold shift in the high tone region is found, it may be expected that consequently peracute speech, which as we know, has been constructed out of mainly high tone components will be less easily understood than appeared to be the case in normal hearing persons.

Because hearing thresholds of persons with a noise-induced hearing loss, unlike those of normal hearing persons, may show large variations, it was not our intention to compose an articulation curve. We were rather concerned with the investigation after the function of speech hearing in a specific part of the tone scale for a group of persons all handicapped by a perception impairment of equal etiological nature.

Status of hearing of the persons tested

Thanks to collaboration with the Medical Service of the Association of the Netherlands Coalmines a speech audiometrical test could be performed with the aid of peracute speech in a number of hearing handicapped individuals. On good grounds might be assumed that their hearing losses have resulted directly from the injurious influence of industrial noise on the hearing organ.

In the present case we are concerned with a group of 200 odd male employees varying in age from 20 to 55. To the status of hearing of these persons belonged, among other things, threshold audiograms and speech audiograms. The threshold audiograms had all been made up according to the I.V.-method. Measuring frequencies were 500, 1000, 1500, 2000, 3000, 4000, 6000 and 8000 Hz. In 60 persons measurements were also performed at 2500 Hz. During the subsequent evaluation of the results of this test the great influence of threshold level increases at this last-mentioned frequency on the understanding of peracute speech became evident. For this very reason only the individual results of these 60 persons were included in the elaboration of the results which follows later on in this chapter. For further orientation a group threshold audiogram was made up out of the individual threshold audiograms belonging to the 60 ears which have been tested with peracute speech. (fig. 13)

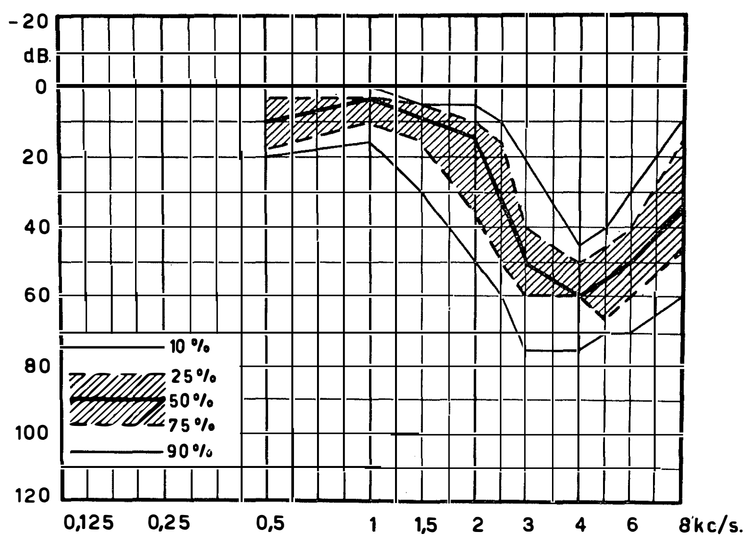


Fig. 13.
Group threshold audiogram of sixty ears tested with peracute speech.

Speech audiograms were made up binaurally, with the aid of Groninger P.B.-lists. Articulation percentages had been determined each time at presenting these lists at intensities of 55, 70 and 85 db.

The concept *group-audiogram* deserves some further explanation. In industrial hygienic circles one often feels the want of being able to compose one single diagram, representing the total number of hearing threshold curves which have been measured in a group of persons employed in the same department. In such a graph the average threshold shift and the spread of results should be expressed.

The so-called *department* or *group audiograms,* as they may be made up in imitation of VAN LEEUWEN meet this want to a certain extent. To achieve this the hearing losses of a number of individual audiograms are measured in db at each measuring frequency (nine in our case). Out of these findings one calculates, for each of these frequencies separately the *median* e.i. the numerical value below or at which 50 % of all the findings lie. One calculates the median rather than the average thus preventing that the most extreme findings should influence the average in a too high degree.

To form an idea about the spread one can apart from the median, also calculate the first and third quartile. These are the numbers below or at which 25 % resp. 75 % of all the findings lie. If required a subdivision in deciles may also be made.

These median and quartile values belonging to the different test frequencies are taken down in the customary audiogram form. The corresponding points for the various frequencies are for the sake of surveyability connected by lines. Proceeding thus, a department audiogram will come into being from which for each measuring frequency the percentual distribution of the threshold level elevations can be read off. It should be emphasized, however, that no conclusions can be drawn regarding the shape of the individual audiogram from the group audiograms having developed in this way.

Analogous to a group threshold audiogram, a group speech audiogram may be made up as well. From the latter one is able to read off, for each intensity with which P.B.-lists are presented, the percentual distribution of the obtained articulation scores.

Test procedure

Seeing that in this case, as we have pointed out before, it was not a matter of composing an articulation curve, the testing method differed in some degree from the one applied in the group of normal hearing persons. In the present case we merely tried to ascertain the lowest position of the attenuator (steps of 5 db.) which enabled the test person in question to attain a maximal articulation score.

This test was also performed monaurally. The contents of the word list were unfamiliar to the subject. Preceding to the actual word list the test person was offered part of a filtered text to be able to acclimatize himself in this way to the unusual and strange character of the peracute speech.

Results of the investigation

Without entering upon the results of the individual tests performed in this manner, mention may be made of the fact that in the majority of cases treated by us, complete understanding of the peracute wordlist was possible, provided that the intensity with which speech was presented was sufficiently high.

With regard to the more precisely worked out test results of some 60 persons, 4 categories may, roughly spoken, be distinguished in this group.

Category 1. (fig. 14, 15) 8 persons.

Some persons handicapped only by slight hearing losses were able to understand the entire word list at an intensity of 45 db. So the conditions under which the maximum articulation score could be reached did not differ from those referring to the group of normal hearing persons.

Category II. (fig. 16, 17, 18) 43 persons.

By far the greater part of the persons examined belonged to this group. These persons as well were able to understand the peracute speech entirely. To this end speech, however, had to be presented at an intensity which was higher than that required for normal hearing persons and for those belonging to category I.

In general we may say: The larger the existing hearing loss along the tone-scale, the greater should be the intensity level at which peracute speech is offered in order to be fully understood yet.

Category III (fig. 19) 5 persons.

The word list appears to be only partly understood by some persons all handicapped by very extensive noise induced hearing losses. This even proves to be the case when speech is presented at maximal intensity (90 db) which is allowed by the apparatus in use. Above the 90 db level objective distortion of the presented sound stimuli will occur. It is this very distortion which may unfavourably influence intelligibility. Therefore, it does not seem improbable that for this category too, complete understanding might be possible provided the apparatus could supply the necessary undistorted output.

Category IV (fig. 20, 21) 4 persons.

Finally there remains a small group of noise deaf persons who found the understanding of speech impossible. In all these cases very serious threshold losses are found.

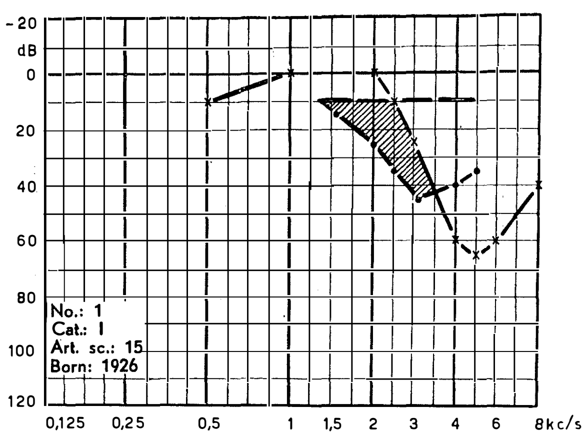


Fig. 14

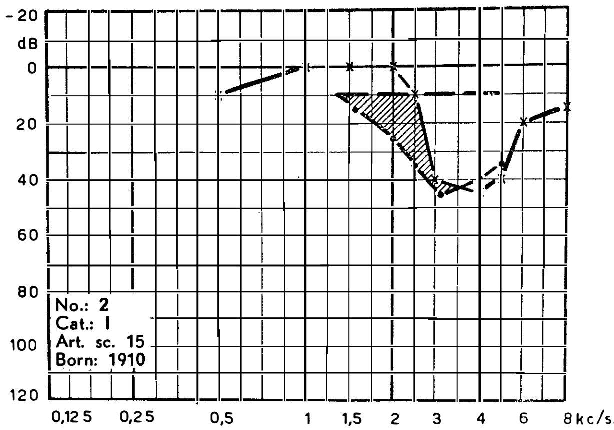


Fig. 15

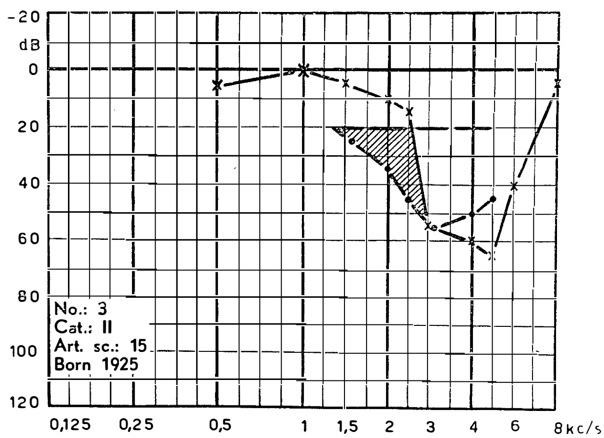


Fig 16

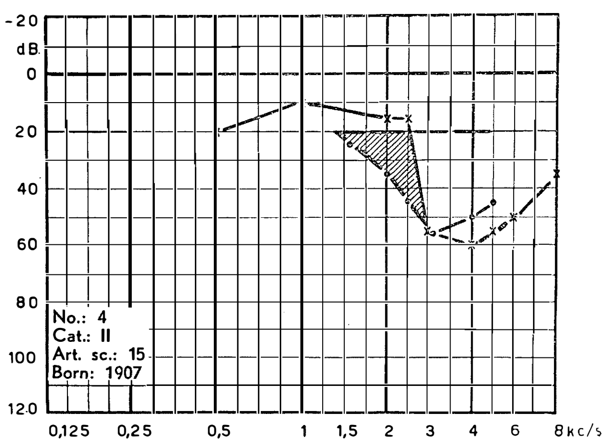


Fig. 17

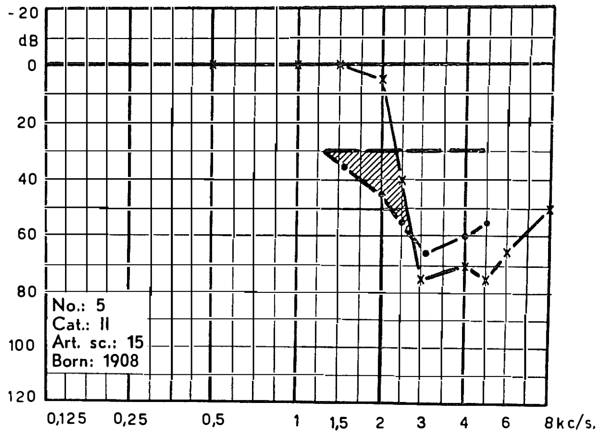


Fig. 18

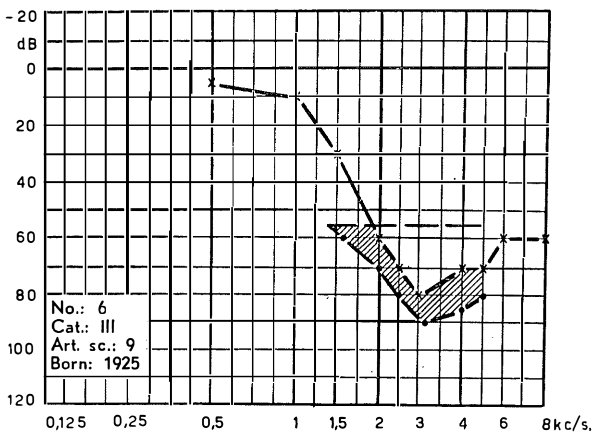


Fig. 19

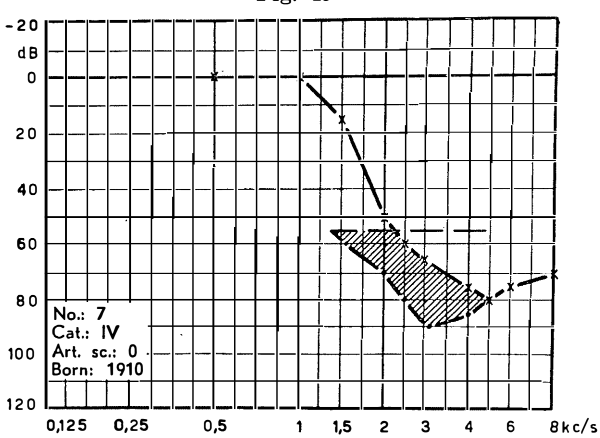


Fig. 20

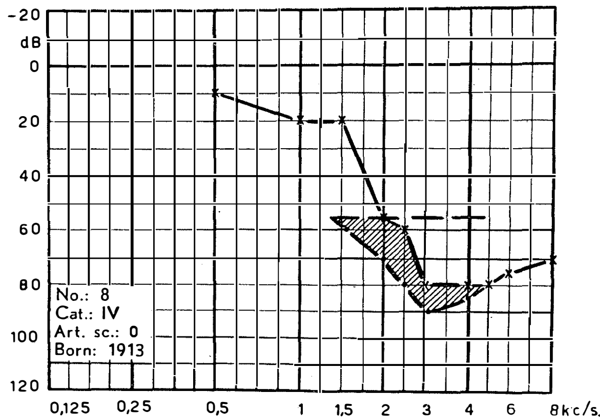


Fig. 21

A further study of the test results.

In the preceding sections only the results of our investigation were discussed. From these it became evident that the great redundancy which characterizes normal speech and speech hearing, makes it possible that so-called "narrow band" speech, as our peracute speech, under favourable conditions may be fully understood. This does not only apply to normal hearing persons but also to the majority of the tested persons with a noise-induced deafness.

We shall now more closely consider the conditions under which this peracute speech may be understood.

On account of the fact that normal speech hearing takes place well above the hearing threshold, it stands to reason that peracute speech too has to be presented at sufficient intensity and therefore sufficiently far above hearing threshold level. In the preceding chapter we saw that the peracute sound pattern consists of a *noise component* and a *signal component* (cp. fig. 11). So the latter part, in fact, comprises the *actual speech* and we might also call it; the *effective speech pattern.* So in order to understand peracute speech the listener has to resort to this speech pattern. Within the peracute sound pattern as a whole there exist certain constant S/N ratios irrespective of the intensity at which the listener is presented speech. This has important consequences with regard to the spectral distribution of the speech pattern as it is presented to the listener at various intensities. As soon as the intensity with which speech is offered is so high that the noise component is also presented above the normal-hearing threshold, the listener's resource to understand peracute speech is all the time the sàme qualitative speech pattern. Further increase of intensity does not augment the informative pattern. This may be elucidated best by fig. 22. We see here that irrespective of the fact whether the peracute sound pattern is offered at an intensity of 35, 45 or 60 db, the effective surface remains constant by the presence of the noise. Consequently, when presenting at an intensity greater than 35 db, the *complete* peracute speech pattern is presented at supraliminal level. It is a different matter when the intensity is lower than 35 db. In these cases only part of the speech pattern or an incomplete peracute speech pattern is presented above normal hearing threshold level.

In our investigations on testing normal hearing persons, using

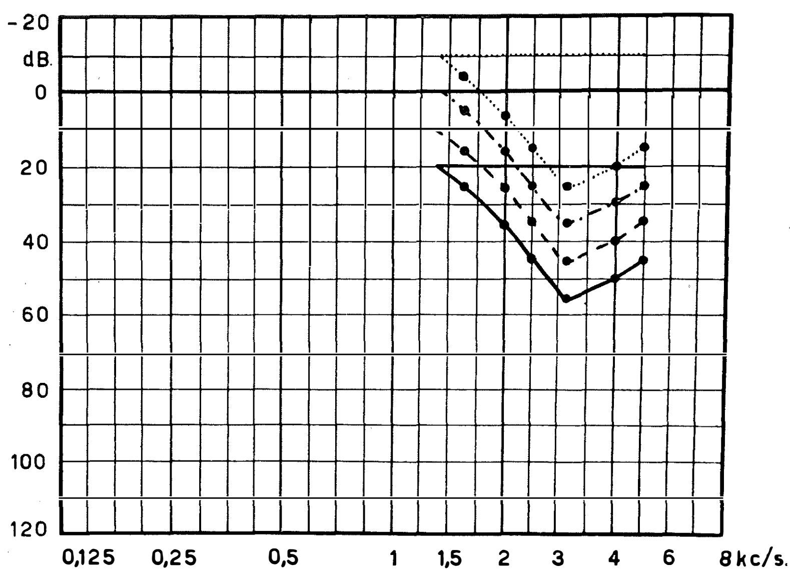


Fig. 22.

Peracute sound pattern presented at 25, 35, 45, and 55 db above normal threshold level.

....	25 db
—.—.—.—	35 db
— — — —	45 db
————	55 db

peracute speech, we noticed that, in order to arrive at a maximal articulation score for all persons, it was necessary to offer speech at an intensity of at least 45 db. Apparently in this case above hearing threshold a speech pattern is presented, the level of which is minimally required for intelligibility. Although qualitatively this is already the case presenting it at an intensity of 35 db, it obviously does not take place sufficiently far above hearing threshold. For hardly any understanding is possible at this intensity.

Up to now we have only reckoned with a normal hearing threshold. In case of thresholds of noise deafened persons, however, we are confronted with threshold level increases for frequencies which, wholly or partly, fall *within* the frequency band of the peracute speech pattern. In order to present a complete speech pattern above such a pathological threshold, the degree of intensity of the peracute speech must be increased proportional to the width and the depth of the dip in the audiogram. It appears now that in some of those cases we examined (Cat. I, fig. 14 and 15) a maximal articulation score can be attained when the peracute speech is presented with an intensity of 45 db. So this is the same intensity as that which was necessary for attaining a maximal articulation score in case of persons with a normal threshold. Considering fig. 14 and 15, we may notice that this maximal articulation score is established in spite of the fact that in these cases the pathological hearing threshold is only crossed in a certain part of the frequency band of the complete peracute speech pattern. In other words, it becomes clear that to a certain extent, even an incomplete speech pattern may still provide the listener with sufficient informative elements to achieve full intelligibility. So it may be stated that the complete peracute speech pattern is characterized by a certain degree of redundancy of spectral energy components.

It will also become clear now that a maximal articulation score can be attained by a person as long as his noise-induced threshold loss is such that when presenting peracute speech with an intensity of 45 db, this pathological threshold is passed far enough in the frequency band belonging to thàt part of the speech pattern indispensable to intelligibility. Test persons handicapped by such hearing losses we classified under category I.

The curve of the hearing threshold on the other hand being such that in this essential part it is crossed insufficiently far or not at all, intelligibility will naturally be impossible. When such is the case, however, intelligibility is improved easily when the intensity at which the peracute speech is offered is increased and that in such a degree that that part of the speech pattern essential for intelligibility will again be presented sufficiently far above hearing threshold. So in general it may be stated that the wider and deeper the dip in the audiogram is, the more the intensity level should be raised. Persons with such hearing losses for whom it appeared necessary to present peracute speech with a greater intensity than 45 db in order to attain a maximal articulation score we classified under Category II (See fig. 16, 17 and 18).

Higher intensities were also needed for persons who were grouped under category III (fig. 19). Full intelligibility, however, cannot be obtained here because at the maximal intensity which the reproduction apparatus in use allowed, still too small a part of the necessary speech pattern was presented at supraliminal level.

Summarizing, it has appeared from the test results of persons classified in the categories I, II and III that a certain degree of incompletion of the peracute speech pattern presented supraliminally does not prevent the test person from attaining a maximal articulation score.

Next the question arises what spectral energy of the peracute sound pattern at least should be presented supraliminally, in order to make the attainability of a maximal articulation score possible. Or, in other terms, we may wonder which part of the complete speech pattern just comprises sufficient informative elements for intelligibility. After a further inquiry into the test results these matters may be ascertained in quite a simple manner. As was the case with measurements by means of $^1/_3$ octave filters, this time again we will consider the sound pattern as having been built up out of a number of subsequent bands, each of them being $^1/_3$ octave wide. The central frequencies of these bands are 1600, 2000, 2500, 3200 and 4000 Hz.

We will now consider the patient whose audiogram is shown in fig. 14. He was grouped under category I because the maximal articulation score was attained by him at presenting the word list at 45 db. On account of the abnormal course of the hearing threshold, in the sound pattern which is now presented supraliminally no spectral energy components above ca. 3500 Hz. appear to be present, while in the 2500 and 3200 Hz bands less energy is present than was the case in the sample offered to normal hearing persons at their attaining a maximal articulation score. So it may be inferred from this that the spectral energy components above 3500 Hz present in the peracute sound pattern, can as a contribution to intelligibility be dispensed with.

In case of the patient whose audiogram is reproduced in fig. 15 (Cat. I) in the supraliminally presented sound pattern hardly any energy proves to be present in the 3200 Hz band. This leads to the supposition that the spectral energy components in the 3200 Hz band of the peracute sound pattern as a contribution to intelligibility may be wholly dispensed with. From the cases 3,4 and 5 (fig. 16, 17 and 18) it becomes quite obvious that this supposition is correct. In these three persons, while attaining full intelligibility, in the supraliminal pattern only components in the bands containing 1600, 2000 and 2500 Hz as central frequencies appear to be present. So it looks as if only spectral energy components in these three frequency bands are essential for obtaining full intelligibility of the peracute speech.

Now we should try to find out to what extent the hearing threshold in these three frequency bands should be crossed before persons with a noise dip in the audiogram may reach a maximal articulation score. To answer this question it is necessary to pay attention to table I. From the persons belonging to cat. I, II and III, whose audiograms have been reproduced in fig. 14 to 19 incl. the amount of db has been reported in this table by which the individual pathological hearing thresholds in the bands 1600, 2000 and 2500 had to be crossed by the peracute speech sounds to make a maximal articulation score — at that intensity level — just possible. At a lower intensity level only a moderate intelligibility could be reached.

TABLE I

Pat. No.	Amount of db above threshold			Intelligibility
	1600	2000	2500	
1	15	25	25	Good
2	15	25	25	Good
3	20	25	30	Good
4	10	20	30	Good
5	35	40	15	Good
6	25	10	10	Poor

In composing this table, we have confined ourselves to this sample of only 6 audiograms from the total group. The reason for that lies in the fact that by means of these very threshold curves the characteristic features which determine the intelligibility of peracute speech, can be expressed so clearly.

The numbers recorded in this table imply that three different situations may occur as regards the degree in which the pathological hearing threshold in the 2000 and 2500 Hz bands is crossed when a maximal articulation score is attained:

a. When the pathological threshold in the two bands is crossed by 25 db, so in the same measure, then a maximal articulation score is reached. (cp. case 1, 2).
b. In case the pathological threshold in the 2500 Hz band is crossed by more than 25 db, full intelligibility is already possible when the threshold in the 2000 Hz band is crossed in a proportionately less degree (cp. case 4).
c. The reverse of the situation described under b. is also possible, namely, when the pathological threshold in the 2500 Hz band is crossed by less than 25 db. Full intelligibility then also is possible provided the threshold in the 2000 Hz band is crossed in a proportionate degree (cp. case 5)

Of course the occurrence of one of these three situations is entirely dependent on the course of the threshold curve.

On the strength of the above-mentioned facts it now seems plausible that the spectral energy components in the two bands which have 2000 and 2500 Hz as central frequencies make an informative contribution, more or less of equal value, to intelligibility. As to the informative contribution afforded by the spectral energy components of the 1600 Hz band it does not seem likely that it is essential for the intelligibility of our specific speech sample. Considering the characteristic shape of the threshold curve in noise-induced deafness, threshold level elevations near 1600 Hz were only slight in the cases we examined, (see fig. 13). Consequently the threshold in this band is generally crossed amply. In spite of that, judging cases 5 and 6, it may be noticed that an ample threshold crossing in the 1600 Hz band, viz. 35 db and 25 db, does not allow decreased threshold crossing in the 2000 and 2500 Hz bands.

We are, accordingly, of opinion that the most important and for the intelligibility of peracute speech indispensable information is supplied by the spectral energy components of the two bands containing 2000 and 2500 Hz as central frequencies.

In this framework the cases belonging to category IV (cases 7 and 8, fig. 20 and 21) deserve to be discussed separately. On the basis of the knowledge acquired from the preceding discussion concerning the cases grouped in categories I, II, III we may expect that for these cases too some or even full intelligibility is possible. On the contrary, intelligibility proves to be nil. So in this case one might speak of a total *discrimination loss* for peracute speech. The cause of these discrimination losses may next be wondered at.

In the foregoing chapter we already observed that besides the incompleteness of speech sounds as other possible causes of discrimination loss may be mentioned:

a. Disturbance of the spectral energy balance
b. Recruitment
c. Inactivity of the discrimination ability in part of the tone scale.

The first factor, disturbance of the energy balance, is in our case not to be considered for causing discrimination loss. For the very characteristic of peracute speech is the absence of the relatively strong bass components occurring in normal speech. Masking of the relatively weak components in the treble region is therefore not to be expected. On the contrary, in peracute speech one could rather speak of relatively strong components in the high pitch-range.

As regards recruitment a phenomenon wich may ever be noticed in noise deafness, the following may be remarked. Disturbed loudness-ratios which as a result of recruitment arise within the peracute sound pattern, may, in view of the very vulnerable character of peracute speech, easily exert an evil influence on intelligibility. This does not hold good, however, when recruitment occurs at a substantial rate only at those frequencies which are not essential for intelligibility. From the foregoing observations we learnt that these are the frequencies higher than ca. 3000 Hz. Taking into account the fact that a maximal intelligibility was possible in the categories I, II, III, it does not seem correct to assume that the existing recruitment influences intelligibility in some degree.

Finally the discrimination loss may be caused by the phenomenon which has been alluded to in the preceding chapter. What we mean is the occurrence of a shift or transfer of the discrimination ability to another part of the tone scale. In case of hardness of hearing discrimination ability in a certain part of the tone scale may grow inactive in the course of time. The cerebrum of the person concerned has in that case been compelled to focus itself more and more on discrimination of components in that part of the tonescale which is still active in contributing to intelligibility. In some cases this may take place even in a relatively short period of time.

Though, unfortunately, we do not dispose of the necessary anamnestical data to verify this statement it may be assumed on account of the serious character of threshold increases of the cases belonging to category IV, that we have to do with hearing losses having existed for a long time already. Therefore in all probability there is such a partial discrimination loss in the zona acuta of the cases belonging to category IV. Owing to the lack of bass components in peracute speech, discrimination becomes impossible in such cases. It is not quite clear, however, why in these cases this partial discrimination loss is found, whereas discrimination remains undisturbed in other cases (e.g. case 6, cat. III) where at least quite as severe a hearing loss may be detected. Possibly it may be a matter of inactivity atrophy of neurons of the higher auditory nervous pathways. This on the analogy of conceptions which try to account for disproportionately large discrimination losses occurring in some patients suffering from presbyacusis. (SCHUKNECHT). Yet it should not be inferred from this that such an atrophy may be the result of a noise trauma. For though noise deafness has been diagnosed in the cases belonging to category IV, this does not mean to say that these severe perception losses may not also originate from another etiological source as e.g. presbyacusis.

Control-experiments.

From the preceding section some important facts emerged based on speech audiometric tests with the aid of peracute speech. It could be proved, among other things, that the spectral energy components of peracute speech within the two $^1/_3$ octave bands, with central frequencies 2000 and 2500 Hz, supply an indispensable informative contribution to intelligibility.

The qualitative contribution of each of these bands separately seems to be almost of equal value. The quantitative contribution will vary. The components of the bands with 3200, 4000 and presumably also 1600 Hz as central frequencies, on the other hand, appear to afford a redundant contribution if 2000 and 2500 Hz are functionally fully present. It seemed to be worth while to test the accuracy of these conclusions by means of a simple experiment.

For this experiment once more $^1/_3$ octave band filters (BRUEL & KJAER) were used. The testwords in their unprocessed condition were now filtered with the help of these $^1/_3$ octave filters. First of all the 2000 Hz filter was used. The words filtered in this way were listened to by means of head phones after which an intensity level was adjusted at which the words are only *just* understandable for a normal ear. Without the intensity level having changed was switched over to another filter, after which intelligibility was measured again. Successively the 2000 Hz, 2500 Hz, 1600 Hz and 3200 Hz filter were switched on. As regards intelligibility the following results were recorded:

1600	Hz	filter	—	poor	intelligibility
2000	„	„	—	good	„
2500	„	„	—	„	„
3200	„	„	—	poor	„

The results show that intelligibility of *these* specific words is the same in the 2000 and 2500 Hz bands.

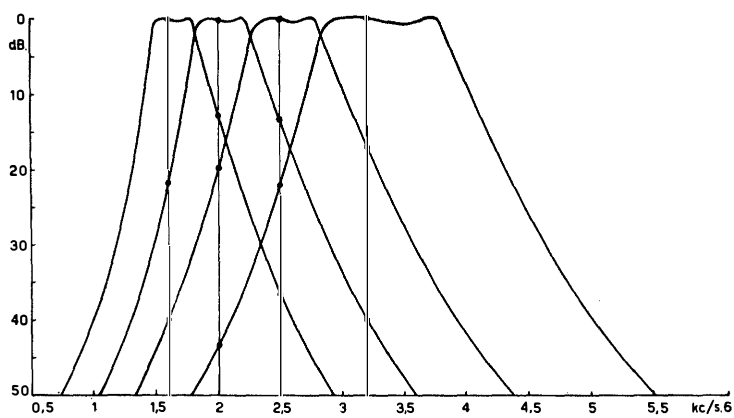


Fig. 23.
Filter-characteristics for four 1/3 octave band pass filters.
(central frequencies resp. 1,6, 2, 2,5 and 3,2 Kc/s.

Choosing the 2000 Hz filter, energy is maximally passed at 2000 Hz. At 2500 Hz relatively less energy is then transmitted. For the reverse is true that having switched on the 2500 Hz filter, energy is maximally transmitted at 2500 Hz, while in that case less energy is passed at 2000 Hz. (cf. fig. 23). In order to understand these words it appears to be of no consequence, however, whether energy is maximally passed at 2000 Hz or at 2500 Hz. The most important fact is that sufficient spectral energy components are transmitted, both in a qualitative and in a quantitative sense. This becomes clear when resp. the 3200 Hz and 1600 Hz filters are switched on. Both filters considerably weaken the spectral energy components near 2000 and 2500 Hz. This results in a strongly diminished intelligibility. It may be inferred from this that the spectral energy components in both the 2000 and 2500 Hz band are indispensable to intelligibility. Consequently this perfectly agrees with the conclusions we arrived at after studying the results of other, though much more elaborate experiments in patients afflicted by noise deafness and normal hearing persons.

Final conclusions to be drawn from speech audiometric testing with peracute speech.

Planning the present investigation we started from the question which could be the principal factors involving discrimination losses in persons with a noise induced deafness. Consequently the question whether it is possible to improve this decreased speech hearing by means of selective amplification came also up for discussion. This requires an investigation after the degree in which in cases of noise deafness a change in the spread of discrimination along the tone scale might occur. In this respect the above described tests with the aid of peracute speech have yielded some important data.

Peracute speech, as being used by us, appears to be understood well by normal hearing persons provided it is presented at a sufficient intensity level. Thus intelligibility appears possible although the main weight of the spectral energy almost entirely lies in such a narrow part of the tone scale. This phenomenon is i.a. due to the fact that in choosing the test material a favourable phonemic structure has been taken into account. In peracute words characteristic high-pitched phonemes are found. In case of threshold shifts in the corresponding region as occurring after noise traumata, intelligibility of these peracute words will thus be disturbed first. However, it has become apparent from our speech audiometric tests performed on a number of noise deafened individuals that this intelligibility decreases only then when threshold shifts occur at freqencies below 3000 Hz. Essential for intelligibility proved to be the spectral energy components between ca. 1800 and 3000 Hz. Threshold losses at these frequencies involve decrease of intelligibility. In the majority of cases we examined this diminished intelligibility appears to be only the result of a slighter peripheral differentiation of the speech patterns. This causes too great an incompletion of the peracute sound patterns presented to the cerebrum. The fact that by a simple amplification of the peracute sound patterns intelligibility again improves to normal made this clear. For such an amplification would not have been effective if other factors as well had cooperated in bringing decrease of intelligibility. As such a causative factor we could mention e.g. recruitment. Accordingly we think we may, among other things, conclude from this that recruitment, as it occurs in noise deafness, does *not* influence intelligibility. Neither the intelligibility of peracute speech, nor the intelligibility of normal speech.

From the tested group of persons suffering noise-deafness, the greater part appeared to be able to gain an optimal intelligibility after sufficient amplification of the peracute speech sounds. This is not the case, however, when we are concerned with normal speech sounds. In many cases uniform amplification of normal speech sounds does not lead to an optimal intelligibility. This appears i.a. from the fact that in many of the tested patients afflicted by noise-induced deafness, we encountered substantial discrimination losses which could be shown by means of speech audiometric tests with the aid of P.B.-lists. To form an idea of these discrimination losses fig. 24 be referred to. A group speech-audiogram has been reproduced here, constituted out of the available binaural speech audiograms. Our investigation with the use of peracute speech was carried out monaurally so that we realize that this group audiogram cannot be a true record of the discrimination losses in one ear. In view of the fact, however, that in all cases practically symmetric hearing losses were found each time, we may indeed assume that from this group

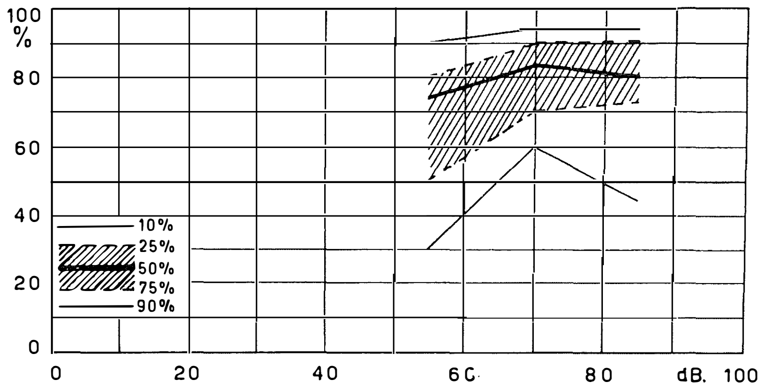


Fig. 24.
Group speech audiogram of sixty ears tested with peracute speech. (P.B.-lists offered at 55, 70 and 85 db).

speech audiogram we gain an impression as to the monaural discrimination losses.

How can we account for these discrimination losses for normal speech when they do not occur in a generally strange and uncommon speech as peracute speech. It has already been pointed out that discrimination losses can also be caused by a disturbance of the spectral energy balance existing between the speech energy concentrated respectively in the bass part and the treble part of the tone scale. In the typically abrupt shape of threshold audiogram, as occurring in noise traumata, diminished intelligibility may ensue from subjective masking. The bass components will then mask the descant components which are informatively of so great an importance but which are perceived poorly. With uniform amplification of normal speech this disturbed energy balance will remain the same; consequently intelligibility will not improve. In peracute speech, on the other hand, in which as we know the bass components are lacking, the factor subjective masking may be left out of consideration as being the cause of diminished intelligibility. So in case of reduced perception of high speech sounds the intelligibility of peracute speech may easily improve by amplification.

Now when discrimination of the amplified high speech sounds is possible then an optimal intelligibility of normal speech sounds should also be achievable. This can only be effectuated, however, by selective amplification of those spectral energy components which are perceived poorly. It became evident, however, that even for the understanding of very high-pitched words no essential contribution is made by spectral energy components out of the frequency area above 3000 Hz. So it follows that in order to reach optimal intelligibility, amplification in this frequency area is not necessary.

When returning now to the question which might be the most important factors leading to discrimination losses in noise deafness, our view at present is that on the strength of what was said above we may conclude that discrimination loss is always the result of a disturbed spectral energy balance. This does not apply, however, to all the cases we examined, since contrary to what was true for the persons we mentioned above (categories I, II, III) it appeared that in some cases intelligibility of peracute speech did not improve (Category IV) by amplification. This only holds for some individuals having very severe and therefore in all likelihood very long-term hearing losses. We are of opinion that the reason why these persons fail to understand anything is lain not so much in a disturbed energy balance but that the cause is rather a partial discrimination loss in the treble part of the tone scale. It seems that in these cases the discrimination ability has in the treble part become completely inactive. For the understanding of normal speech the cerebrum of these persons will thus direct its attention to the discrimination of speech components from the still actively contributing part of the tone-scale. These components are, however, lacking in peracute speech so that discrimination is impossible.

On the strength of these conclusions it must be emphasized that in judging speech hearing in severe types of noise deafness, special attention should be directed to the spread of discrimination-ability over the various parts of the tone scale.

Chapter V

THRESHOLD LOSS AND SPEECH HEARING

In the first chapter was mentioned that for a quick judgment of speech hearing in case of deaf persons and particularly in patients with a noise-induced deafness, it would mean an enormous gain of time when with regard to it some conclusions could be inferred from the threshold audiogram. This at the risk of stating inaccuracies by drawing conclusions about speech hearing on this basis.

It will especially serve the interests of industial hygienic circles when with respect to this a clear correlation can be proved between threshold loss and speech hearing loss in a characteristic deafness as noise deafness.

Various methods have already been indicated to the way in which inferences may be drawn, concerning speech hearing, from the data yielded by the threshold audiogram. None of these methods, however, appeared to be sufficiently reliable as a substitute of the speech audiogram. That is why we finally want to discuss which prospects the investigation with the use of peracute speech offers us in this respect. It is not our intention to try to introduce a new method. What we do want to try is collecting data adequate in so far that they enable us to gain an impression of speech hearing on the basis of the threshold loss for pure tones in case of a specific deafness as that originating after exposure of the hearing organ to industrial noise.

Speech audiometric testing in a qualitative sense, as described in the preceding chapters, has in a considerable degree, deepened our insight into the factors causing discrimination losses and decreased intelligibility in persons suffering from noise deafness.

One of the things which became clear to us e.g. was that, in fact, only the spectral energy components which normal speech under 3000 Hz comprises, are primarily important to speech understanding. It also appeared from our investigation that severe discrimination losses as we may often come across in noise deafness, are not so much the result of diminished speech hearing *capacity*. It is rather a matter of a diminished speech *intelligibility*. By means of our speech audiometric tests with peracute speech we have succeeded in demonstrating that this decreased speech intelligibility is for the greater part the result of a disturbance of the spectral energy balance. The degree of disturbance of this energy balance in case of noise deafness is consequently determining for the amount of discrimination loss for normal speech.

It would be of practical importance when such a correlation between threshold audiogram and speech audiogram could be proved that, according to data supplied by the threshold audiogram, the degree of disturbance of this energy balance might be ascertained. This then makes it possible to state approximately which threshold loss may still be tolerated before disturbance of the energy balance will occur, involving discrimination loss.

To find an answer to this question it will be necessary to compare the threshold audiograms of a large number of persons with a noise-induced hearing loss with the corresponding speech audiograms. At this investigation we disposed of the results of routine tests performed on a large number of male employees of the Association of the Netherlands Coalmines. From these test results we selected the status of hearing of 162 persons. On the basis of the results of these hearing tests noise deafness was diagnosed in all persons.

To the status of hearing belonged:

1. Anamnestical data.
2. Threshold audiograms of both ears.

In this selected group of 162 persons practically symmetric hearing losses were found in all cases.

Conditions during the test were such that the median threshold values at measuring frequencies between 1000 and 8000 Hz amounted to 5 db above average normal in case of normal hearing persons.

3. Binaural speech audiograms.

These audiograms were made up with the help of Groninger P.B.-lists. Articulation scores were determined by presenting these lists with intensities of 55 db, 70 db and 85 db. Each time the S.A.I. (see chapter I) was calculated from the established articulation scores. Conditions during these routine tests were such that the median articulation scores which could be reached by normal hearing persons came to 95% at the three intensities mentioned. The median S.A.I. value for normal hearing individuals thus amounts to 95 %.

In this connection it is interesting to mention that this does not only apply to persons using the normal Dutch vernacular language but also to persons using the *Limburg* (one of the Dutch provinces) dialect.

According to the computed S.A.I. values the above-mentioned 162 persons were divided into 4 groups: A, B, C and D.

To group	A.	(S.A.I.	80-100 %)	belonged	64	persons
„ „	B.	(„	65- 80 %)	„	57	„
„ „	C.	(„	50- 65 %)	„	28	„
„ „	D.	(„	20- 50 %)	„	13	„

Group speech audiograms were composed out of the total number of speech audiograms belonging to each group. In an analogous manner group threshold audiograms were made up out of the total number of threshold audiograms.

For the accomplishment of these group threshold audiograms we chose if necessary the test persons better ear realizing, however, that as a matter of fact we commit the error of assuming that binaural hearing is identical to monaural hearing with the better ear. Our investigation might possibly have gained in reliability if we had the disposal of monaural instead of binaural speech audiograms.

The group audiograms, composed in this way, eight in total, have been reproduced in fig. 25 to 28 incl. Besides the median values we have also recorded the values for the first and third quartile. In the customary manner the corresponding quartile and median points have been connected by lines. The median curves which in this way came to being have been laid down once more, this time separately, in fig. 29 A and B. In fig. 29 A the median curves of the four group threshold audiograms, in fig. 29 B the median curves of the four group speech audiograms. Naturally such a median curve cannot be looked upon as an individual audiogram belonging to one of the 162 persons. Nevertheless, a median curve as reported in fig. 29 A may be regarded as the threshold audiogram of anybody who on the strength of his S.A.I. may be classified under the group pertaining to

GROUP
THRESHOLD
AUDIOGRAMS

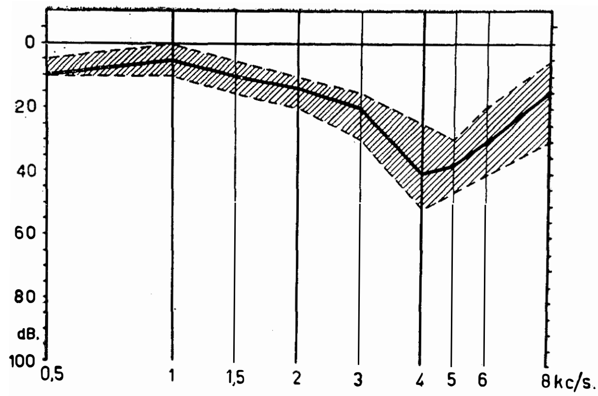


Fig. 25A

Group
S.A.I
64

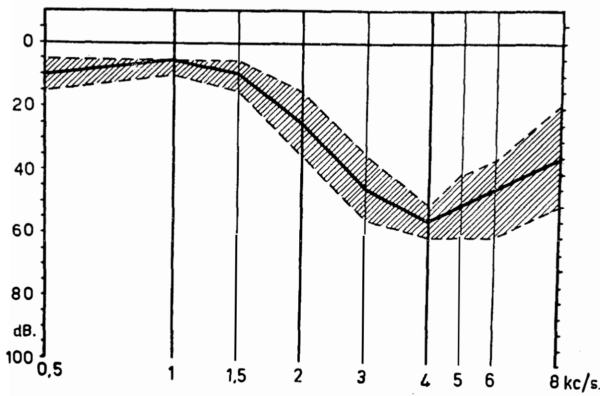


Fig. 26A

Group:
S.A.I
57

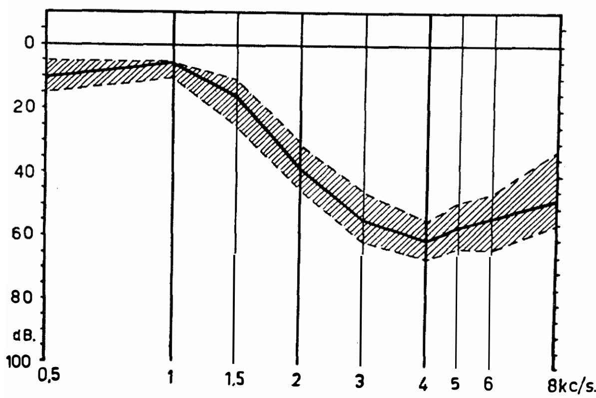


Fig. 27A

Group:
S A.I
28

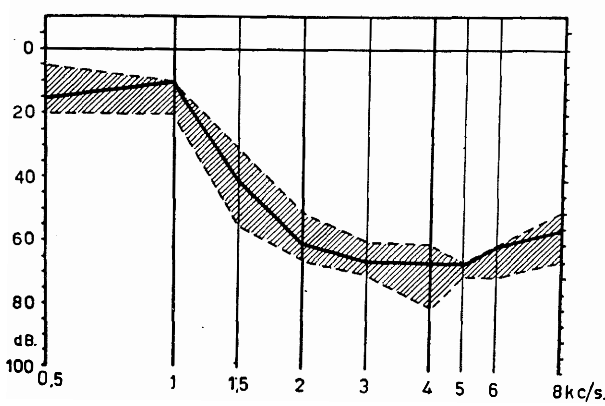


Fig. 28A

Group:
S.A.I
13

GROUP
SPEECH
AUDIOGRAMS

A
80-100 %
persons

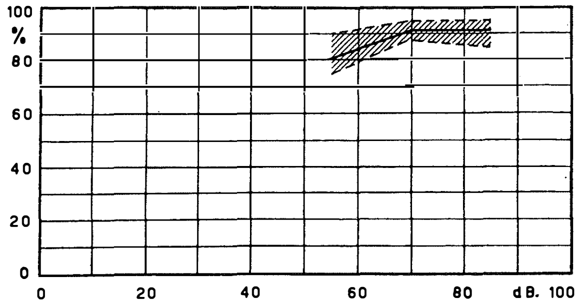


Fig. 25B

B
65-80 %
persons

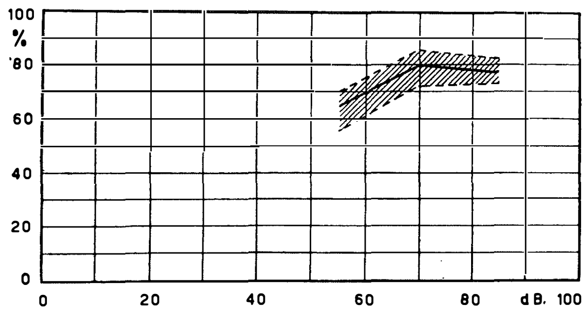


Fig. 26B

C
50-65 %
persons

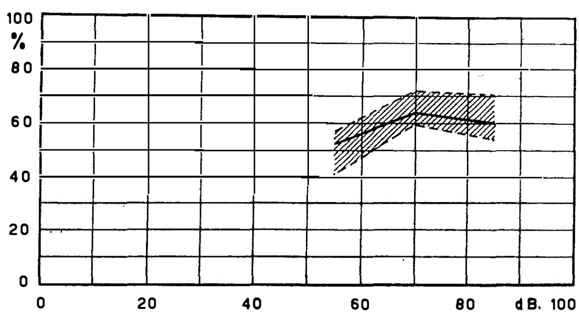


Fig. 27B

D
20-50 %
persons

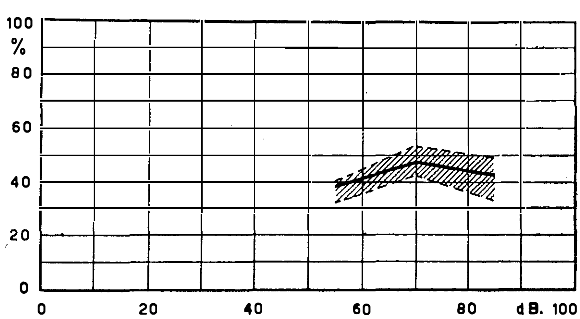
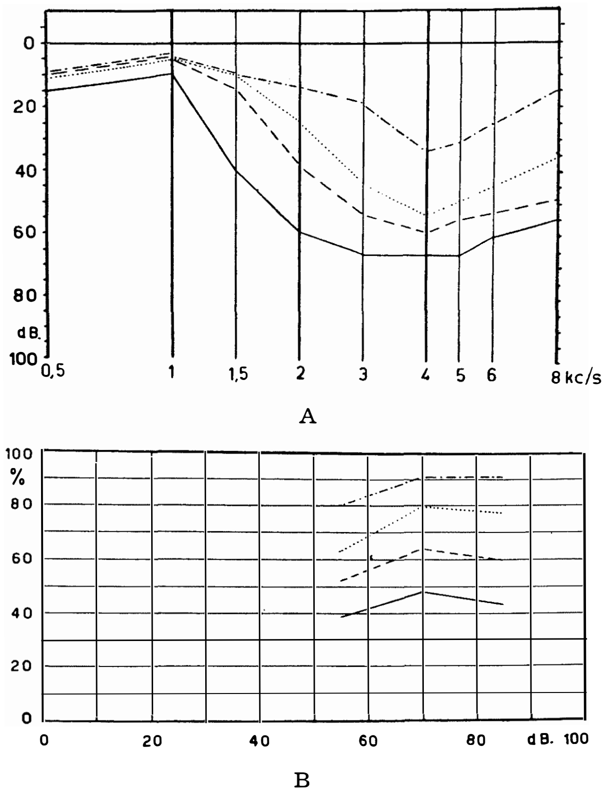


Fig. 28B



S.A.I. : 80-100 %
S.A.I. : 65- 80 %
S.A.I. : 50- 65 %
S.A.I. : 20- 50 %

Fig. 29.

this median curve in question. This S.A.I. then migh have been computed from the articulation percentages belonging to the curve of the corresponding group in fig. 29 B. In other terms, the corresponding median curves in fig. 29 A and B may represent random threshold and articulation curves, which, however, belong to the four different groups.

In the preceding chapter we reported that for the understanding of normal speech only the spectral energy components up to 3000 Hz contribute essential information. It is therefore important to mention that the four median curves from fig. 29 A never cross each other in this frequency area. So this justifies the important conclusion that if the speech audiogram deteriorates, this will also be the case with the threshold audiogram in the frequency area 1000 to 3000 Hz. In other terms, a clear correlation exists in noise deafness between the threshold loss for pure tones (between 1000 and 3000 Hz) and the decrease of the articulation score.

Concerning the median values of the articulation percentages which could be obtained in the four groups we may infer from fig. 29 B that the highest median-scores are reached each time at 70 db. Presenting P.B.-lists at a higher intensity, namely 85 db, an equal median articulation-score is attained at best but in most cases it will be lower. Roughly speaking, we may say that the median value for the articulation percentage which each group may achieve at 70 db may be considered an index for the median value of the discrimination loss occurring in each group.

We know that in the circumstances a median articulation decrease of 5 % at 70 db can still be regarded as normal. It may now be concluded from fig. 29 B that with respect to this 5 % the following median discrimination losses exist in the four established groups.

Group A:	D 4 %
„ B:	D 15 %
„ C:	D 31 %
„ D:	D 47 %

It seems to be of some practical importance to emphasize the relation which could be indicated between threshold audiograms and speech audiograms in this group of 162 random cases of noise deafness, by representing it in a graph. Such a graph is shown in fig. 30. In this fig. the above-mentioned median discrimination losses have been plotted out as function of a number of numerical values which in our four groups A, B, C and D represent the average steepness (db/octave) of the corresponding median threshold curves within three frequency areas, viz. 1000-1500, 1500-2000 and 2000-3000 Hz. Within this region of the tone-scale which is so extremely important for the intelligibility of speech, median threshold level elevations occur in each of the four groups as compared to the median threshold curve of normal hearing persons. The latter threshold level will amount to 5 db above average normal in the circumstances in which the audiograms were taken. Reckoning from this threshold for normal hearing persons the values of the average steepness of the four median threshold curves drawn in fig. 29 A will then amount to:

Group A:	10	db/octave.
Group B:	27	db/octave.
Group C:	33	db/octave.
Group D:	37	db/octave.

From the shape of the curve drawn in fig. 30 may be inferred that the discrimination loss increases in proportion to the increase of the average steepness. The rate of increase of this discrimination

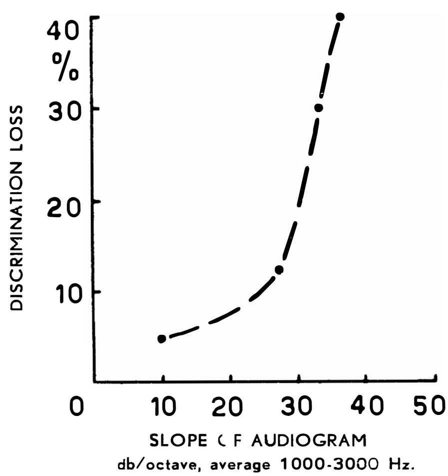


Fig. 30.
Relation between discrimination loss and the slope of the threshold audiogram.

loss is the greater as the numerical value expressing the average steepness becomes larger. This non linear augmentation of discrimination loss becomes obvious when we recall to mind the main cause of discrimination loss in noise deafness, namely the disturbed spectral energy balance of bass-part and treble-part components of normal speech. It goes without saying that as the resulting masking effect of the normally perceived bass part components on the poorly perceived treble part components increases, the discrimination loss will become larger. Such a masking effect strongly depends upon the slope i.e. the steepness of the threshold audiogram. The steeper the slope of the threshold curve, the greater the masking, resulting in a larger discrimination loss.

We should now revert to the starting-point of this comparative investigation, viz. the question which threshold loss may still be admitted before a disturbance of the energy balance will arise.

From the curve shown in fig. 30, only four points are known. So unfortunately it is impossible to indicate at which steepness of the threshold audiogram the discrimination loss just fails to occur. It is possible, however, to ascertain that a steepness of 10 db/octave already implies a slight degree of discrimination loss, viz. 4 %. So it may be assumed that an average steepness not yet amounting to 10 db/octave in the frequency area 1000-3000 Hz already suffices to bring about a disturbance of the spectral energy balance, bass part/ treble part. This holds for the over-all intensity of speech being 70 db. At an almost equal conclusion arrived also TASELAAR, be it after investigations of quite different nature.

It should be pointed out that once the hearing threshold curve in cases of noise induced deafness has reached such a steepness, speech hearing will become very vulnerable indeed. For in our discussion we have not reckoned with the presence of possible background noise. It is known that this noise possesses spectral energy mainly in the bass part. Through the presence of this background noise which specially in persons handicapped by noise deafness plays such an important part, the energy balance may easily be influenced in a still more unfavourable degree.

Our finding may be of practical use when in an arbitrary group of persons with a noise induced deafness, one wants to form from the corresponding threshold audiogram, an idea, in some degree well founded, about speech hearing without having to resort to the time devouring speech audiometric test. This does not alter the fact, of course, that making up a speech audiogram remains essential for acquiring individual and more exact data concerning speech hearing of the persons belonging to this group.

A critical value of tolerable threshold loss for pure tones in connection with speech hearing.

By means of the above-described investigations we have succeeded in demonstrating that in noise deafness there exists a correlation between the divergences the threshold audiogram and the speech audiogram show as a consequence of this anomaly. It also appeared possible to indicate at which amount of threshold loss a discrimination loss for normal speech in the form of P.B.-lists may be expected. In case the threshold loss has developed in such a degree that a slight discrimination loss will just be brought about, then in the person concerned there will hardly be any question of a handicap in a social sense. This does not imply, however, that in case of such a slight aberration one may still speak of completely *normal* speech hearing.

First of all the concept *normal* speech hearing as used in this sense, should be defined more accurately. We do not start here from the conception that it is a matter of being capable to follow a conversation in a social sense, but under normal speech hearing we shall understand the ability to comprehend without any exception, *all* current words from Dutch conversational speech when pronounced at spoken voice intensity in a sound-proof room. In view of the principle on which most of the current speech tests are based we want to restrict ourselves to word-intelligibility although speech comprehension as a rule is based on sentence-intelligibility. Considering this point of view it seems important to indicate the threshold level increase for pure tones which is just tolerable before causing abnormal speech hearing. This threshold level increase will henceforth be referred to as the *critical value of tolerable threshold loss in normal speech hearing.* As a matter of course such a critical threshold value only applies to hearing losses having originated after exposure of the hearing organ to industrial noise.

To mark off this tolerable threshold in the auditory field we have to refer back to the results of our investigation with the use of peracute speech on persons handicapped by noise induced deafness. At this investigation a number of so-called peracute test-words was used which on account of their specific phonemic structure are words which will be misunderstood first in case of an increasing high tone deafness. In evaluating the articulation curve of these peracute words in case of normal hearing persons, apart from the intensity at which all the words could just be understood, the intensity at which they could be understood easiest was also determined. This intensity level we compared with the so-called "most comfortable level" which applies to normal speech when pronounced at about spoken voice intensity. The intensity with which peracute speech should be presented in order to reach this level may approximately be equalized with the spoken voice intensity or the intensity level at which some specifically high-pitched words from everyday speech have to be pronounced in order to be understood easiest. As was mentioned in the preceding chapter the most comfortable level is reached in cases of normal hearing by presenting peracute speech at an intensity of 55 to 60 db. In fig. 22 is shown to what extent the peracute speech pattern is then offered above the normal hearing threshold. By virtue of the knowledge acquired in the previous chapter as to the spectral energy components essential for the intelligibility we can easily establish the utmost threshold which may still be tolerated before an increase of the above-mentioned intensity is called for in order to retain a good intelligibility (fig. 31). In case the peracute speech is presented at an intensity of 55 db. to a patient with a noise induced hearing impairment whose threshold loss has reached

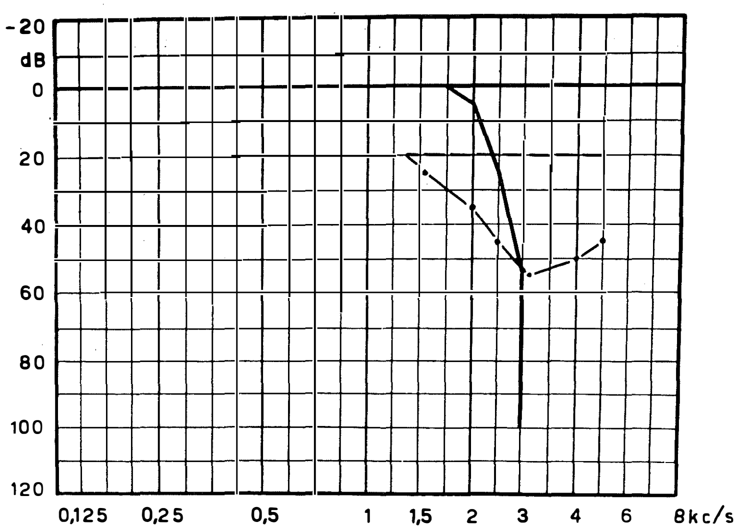


Fig. 31.
Critical value of tolerable threshold loss for pure tones.

this critical threshold value, no spectral energy components higher than 3000 Hz will then be present in the sound pattern offered above this threshold level. The supraliminal energy in the 2000 and 2500 Hz bands then amounts to resp. 30 and 20 db. Referring again to table I (page 70.) we may conclude from it that the energy in these two bands is just sufficient for attaining a maximal articulation score. It may be inferred from this that in case the hearing threshold for pure tones in persons with a noise-induced deafness has reached this critical value, intelligibility of all words, that means also very high-pitched ones, from normal everyday speech is just possible provided that these words are spoken in a quiet environment at a short distance of the listener and at spoken voice intensity. Although in such cases we positively have to do with a noise trauma, it is hardly possible to speak of noise *deafness.* In common parlance, however, the term noise *deafness* is reserved for all persons having a "dip" in the threshold audiogram. So the term deafness is as such not related to any decrease of speech hearing.

The critical threshold for pure tones indicated here, may be of practical use when on the basis of the threshold audiogram one wants to form an idea of the existence or non-existence of a diminished intelligibility for everyday speech. For all that it should be stated that also in that case the making up of a complete speech audiogram remains an indispensable factor for obtaining more exact data.

From the above described investigation it has among other things also become clear however much threshold losses near 2500 Hz may influence speech hearing. It is therefore highly important to point out that in case one wants to form an opinion about speech hearing with the aid of this critical threshold value one must not omit to establish the hearing threshold at 2500 Hz as well. It seems necessary to add this 2500 Hz frequency as regular measuring point to the generally usual measuring points in the so-called I. V. threshold audiometry.

SUMMARY

The current investigation, described in this thesis, deals with some problems specially related to loss of hearing acuity as it may occur in a characteristic perception impairment as so-called noise deafness. As is known exposure to noise can produce a hearing loss, at first occurring as a threshold level increase for high tones. The maximum of such a threshold loss is usually measured near 4000 Hz.

This type of perception deafness often involves severe discrimination losses. Special attention was paid, therefore, to the factors which in this noise deafness may lead to discrimination losses.

To gain an insight into the global discrimination ability for speech, as a rule a so-called quantitative speech audiometric test is performed with the aid of phonetically balanced word-lists (P.B.-lists). Considering the factors causing discrimination losses in certain types of hardness of hearing it may be found useful to carry out a speech audiometric test in a qualitative sense as well. By means of this testing method one may form an idea of the partial discrimination ablility i.e. the discrimination ablility as it is distributed over certain parts of the tone-scale. By means of such qualitative tests it could be ascertained i.a. that in general discrimination ability will be retained best in those parts of the tone-scale where the hearing loss according to the threshold loss is slightest. In some cases discrimination ability even appears to have become completely inactive. One may arrive at such a conclusion by assessing intelligibility in narrow bands of speech. By bands of speech is understood speech of which the spectral energy is concentrated in a limited part of the tone-scale only. These bands of speech which, under favourable conditions, can still be understood by normal hearing persons, may be obtained by using filters. One may influence the understanding of this filtered speech in a favourable sense by compiling word material from selected phoneme-material.

Preferably those phonemes should be chosen the formant-areas of which will fall as much as possible within the corresponding frequency region.

In *chapter III* and *IV* of this thesis experiments are described with the aid of which we tried to investigate in which way the characteristic hearing threshold of a noise-deafened patient influences speech hearing. It was also ascertained in how far in cases of noise deafness a partial discrimination loss may occur in the treble part of the tone-scale. Tested were the intelligibility and speech hearing capacity of those patients for a specific band of speech, characterized by a markedly high-tone character. This band of speech was obtained by filtering and that in such a way that the frequency characteristic of the filter combination which had been used almost mirrored a threshold audiogram specific for noise-induced deafness. So the frequency response area has been chosen thus that the energy could be passed maximally at 4000 Hz. The cut-off frequency of this high-pass filtering was found at ca. 2000 Hz. The slope of the filter curve was ca. 50 db/octave. The words which were filtered had been composed by phoneme choice in such a way that the understanding of this speech still remained possible for normal hearing persons provided under conditions favourable. The speech sample acquired in this way and recorded on tape, was called *peracute* speech. Apart from this strongly mutilated speech which, nevertheless, under certain conditions can be understood, a background noise also appeared to have been recorded. This noise, having come into being as artefact, proved to play a very important part. For measurements of the S/N-ratios existing within this peracute sound pattern, with the help of $^1/_3$ octave filters, showed that this noise component masked all frequencies below ca. 1500 Hz. It followed from this that in peracute speech no low frequencies were present which might have contributed to the intelligibility.

By means of this peracute speech, speech audiometric tests were performed in the customary manner. Subsequently were tested:

a. The course of the articulation-score as function of the intensity in a group of normal hearing persons. In this way an articulation-curve was composed.
b. Intelligibility and speech hearing capacity of peracute speech in

a number of patients handicapped by various noise-induced threshold losses.

With respect to the results of this investigation, four categories could be distinguished in cases of noise deafness:

Category I:

A maximal articulation score could be obtained already when peracute speech was presented at the same intensity as that which appeared necessary for normal hearing persons in order to reach just a maximal articulation score.

Category II:

Full understanding is possible only then when presenting at a higher intensity as that needed for persons belonging to cat. I. To attain a maximal articulation score, intensity had to be increased proportional to the amount of hearing loss.

Category III:

The peracute word list is only partly understood. Nevertheless possibly a maximal articulation score could also have been reached in this case if it had been possible to offer higher intensities with the apparatus in use without bringing about distortion of the presented sound.

Category IV.

To some persons the understanding of peracute speech proved to be impossible. In each of the cases very severe and presumably also long-term hearing losses were found.

Concluding it may be said that in all the test persons handicapped by noise deafness, except the few who were classified under category IV, understanding of markedly high speech sounds remained possible. So in general discrimination ability in the treble part of the tone-scale does not seem to be disturbed by a noise trauma. This has the important consequence that decrease of speech hearing in cases of noise deafness could be eliminated by selective amplification of the speech sounds. Naturally this does not apply to persons with very severe hearing losses (cat. IV). In these cases one may speak of a partial discrimination loss in the treble region. This implies then, that in order to understand normal speech these persons have to resort to the discrimination of speech components from the still actively contributing part of the tone-scale.

Supported by the fact that the spectral constitution of the peracute sound pattern, was known to us quantitatively, as well as qualitatively, on the basis of the results of this investigation we tried to find an answer to the question which factors may be responsible for the occurrence of global discrimination losses in noise deafness. Such because it has appeared that the partial discrimination ability in the high pitch range remains undisturbed apart from some exceptional cases.

In this connection the following could be stated:

1. For the understanding of characteristic high speech sounds from normal everyday speech especially the perception of spectral energy components near 2000 and 2500 Hz is of essential importance. The occurrence of a disturbed perception of spectral energy components near 3000 Hz and higher, as will be the case in an initiating noise trauma, does not hamper the understanding of speech in any respect. Decrease of speech hearing in noise deafness is, accordingly, to be expected only then when the hearing loss corresponding with the hearing threshold for pure tones has extended to frequencies below 3000 Hz.
2. Recruitment as occurring in noise deafness does not appear to hamper the discrimination of speech sounds. So in all probability this symptom only influences the high speech components which, however, do not supply an indispensable contribution to speech intelligibility. The disturbance of the energy balance which normally exists between treble part and bass part appears to be a significant cause for the occurrence of discrimination losses in noise deafness. This involves subjective masking of the weak treble part components by the normally perceived strong bass part components. It stands to reason that the presence of background noise, most energy of which is found in the bass part, will even more influence this disturbance in an unfavourable sense.
3. By making use of the foregoing conclusions it appeared possible to indicate a so-called critical value of tolerable threshold loss for pure tones before speech hearing is influenced *(chapter V)*. This will mark off the auditory field in such a way that as long as the decreased hearing threshold level for pure tones, caused by the noise trauma, has not crossed this critical threshold value,

one may still speak of normal speech hearing. By normal speech hearing in this connection is meant the capacity to understand without any exception all current words from colloquial speech when pronounced in a sound-proof room at spoken voice intensity. This critical value of tolerable threshold loss may be of practical use when with the aid of the threshold audiogram only, one wants to form an idea of speech hearing in case of noise-deafened patients. In case one should want to use this curve in practice it is necessary to determine the threshold at 2500 Hz as well in making up the threshold audiogram.

By comparison of group threshold audiograms of a number of arbitrary cases of noise deafness with the corresponding group speech audiograms, we could show next that there is a certain correlation between the threshold loss for pure tones within the frequency area 1000-3000 Hz and the decrease of speech hearing. This relation is graphically reported by plotting out the decrease of speech hearing expressed in percentual discrimination loss as a function of the average steepness/octave of the pure tone threshold curve within the frequency area 1000-3000 Hz. From the curve which in this way has come into being, it becomes apparent that there does not exist a linear relationship between slope and discrimination loss. It becomes also clear, that an average steepness of only 10 db/octave already suffices to cause some discrimination loss c.q. an annoying disturbance of the energy balance. The influence of possible background noise has been left out of account.

Above-mentioned findings may be valuable in judging speech hearing of a number of patients with a noise-induced deafness on the strength of the data yielded by the corresponding group threshold audiogram.

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